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THE EFFECT OF LAND USES ON LAKE WATER QUALITY

STURGEON LAKE, ALBERTA

by

© ANN ISABEL MALLANDAINE

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled THE EFFECT OF LAND USES ON LAKE WATER QUALITY - STURGEON LAKE, ALBERTA submitted by ANN ISABEL MALLANDAINE in partial fulfilment of the requirements for the degree of Master of SCIENCE.

DEDICATION

To my mother
for giving me a dream

To my father
for showing me the way

and To my husband
for helping me through

ABSTRACT

This study was conducted in the Sturgeon Lake drainage basin. The objectives were to increase the water quality data base and to relate the findings to land uses in the watershed. This would improve the reliability of management plans for the lake area.

A resource inventory of the watershed components was compiled and correlated with water quality data collected from a dozen sample sites over a three month period.

It was found that the lake is naturally mildly eutrophic with most of the nutrient inputs coming from natural sources. Man-induced changes in water quality were virtually undetectable over the natural variations. Anthropogenic effects are further masked by the fact that many of the intensive land uses are located near areas where water quality is naturally of a relatively poor quality.

Primary productivity in the lake was found to be limited by physical factors such as color, turbidity and self-shading rather than nutrient availability. Large phosphorus concentrations relative to nitrogen concentrations favor blue green algae populations.

Lake levels are maintained at an excessively high level in order to maintain a water supply for the town of Valleyview. As a result, good beach areas are flooded for most of the year and many shorelines are being eroded. Alternate means of supplying water to the town are suggested.

Development capacity calculations indicate that the lake is near the optimum level of development. Shoreline development should be

discouraged but there is potential for more day use and backshore development. Possible areas for some development are recommended.

Recommendations are also made regarding wetland drainage and lake restoration techniques. Possible subject areas meriting further study are suggested.

ACKNOWLEDGMENTS

There are many people whose aid in this project made it considerably easier to complete than it might otherwise have been.

Dr. A.H. Laycock, my thesis supervisor, assisted me during all stages of this research. His continued support and advice was greatly appreciated. Special thanks also go to Dr. Mike Hickman who helped to guide me over some of the more troublesome spots in my analysis and made a large amount of published and unpublished data available to me. I would also like to thank Dr. Ed Jackson for consenting to be on my thesis committee.

The Planning Division of Alberta Environment, through Mr. Nico Van der Giessen of the Grande Prairie office, provided financial support for the field season. Mr. Van der Giessen also advised me regarding some technical problems encountered during the field season.

Field equipment was lent to me by the Departments of Geography and Zoology at the University of Alberta. Much unpublished data and many reports dealing with Sturgeon Lake were made available to me from the files of the Peace River Regional Planning Commission. The assistance provided by Al Farrants and Alex Frank, Fish and Wildlife officers in Valleyview, was invaluable. When the lake was too rough to use a small boat safely, they kindly took me around the lake in their boat and assisted in the sample collection. My husband, Tim, also assisted me during the field season and spent many hours building, adjusting and repairing equipment. He was also able to introduce me to many people

and places of interest as he spent many summers with his grandparents, Mr. and Mrs. Fred Young, at what is now Young's Point Provincial Park. The equipment at the Pollution Control Division Water Quality laboratory was made available to me for the analysis of my chlorophyll a samples. Mr. Scott Livingstone kindly assisted me in this procedure and helped me with the calculations involved.

Michelle Mallandaine, my sister-in-law and typist, deserves a special note of credit for the tolerance, perseverance and skill which went toward the final preparation of this thesis.

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CHAPTER 1

INTRODUCTION

Everything changes with the passage of time, some things rapidly and others more slowly. Mountains are found where once there were oceans or great lakes. Huge glaciers pushed forward across the land and, when they disappeared, left a landscape very different from the one they first covered. Species of plants and animals have developed and some have become extinct. Flowers have bloomed, spread their seeds and died. Rivers have run across the land, changing courses whenever an easier route was found, eroding channels into the earth as they went. Lakes were formed and, as they age, have begun to fill in to become solid ground.

The aging of one particular lake located in the Peace River Region of Alberta is the topic of study for this thesis.

1.1 STUDY OBJECTIVES

This study deals specifically with Sturgeon Lake and its drainage basin. It is one of the few lakes in the Peace River Region which is regarded as being good for a variety of recreational uses. It also supports a commercial fishery, provides much of the livelihood for an Indian Band and is a source of water for a nearby town. As such, the maintenance of reasonably good water quality is of prime concern.

The aim of this research is to increase the available data base for the lake and its watershed so as to reduce some of the uncertainty and improve the reliability of the management plans for the lake. I will provide a season of detailed water quality information and

analyze the data to characterize the present trophic status of the lake as accurately as possible. I will also assess the nutrient and sediment load reaching the lake and estimate the relative contributions of them from various sources. By estimating the development capacity of the lake on the basis of the data gathered, it will then be possible to provide some guidelines for management of the area.

1.2 HISTORY OF THE STUDY AREA

Sturgeon Lake originated during the Pleistocene after glaciation. In the midst of the new, post-glacial landscape, this lake formed in a depression that was an extension of a buried bedrock channel. A few small streams drained into it, carrying suspended silts and clays from the land around the lake. This young lake, which eventually would come to be known to man as Sturgeon Lake, was beginning to age.

As the climate continued its warming trend, plants began to appear, their seeds having been carried to the new locations from ice free areas on the wind or on the coats of animals which moved in as the ice left. Over several hundreds of years and many more climatic variations of different magnitudes, the variety and numbers of plants and animals gradually increased and changed through the process of succession until the ecosystems seen today in the drainage basin were established.

A similar pattern was set up in the lakes and streams. Aquatic plants were established, sometimes thriving and sometimes succumbing to the competition from other plants. Phytoplankton, phytobenthos, macrophytes, zooplankton and fish were all established and nature's cycles linked them together.

All of these ecosystems are still in a state of flux, responding to

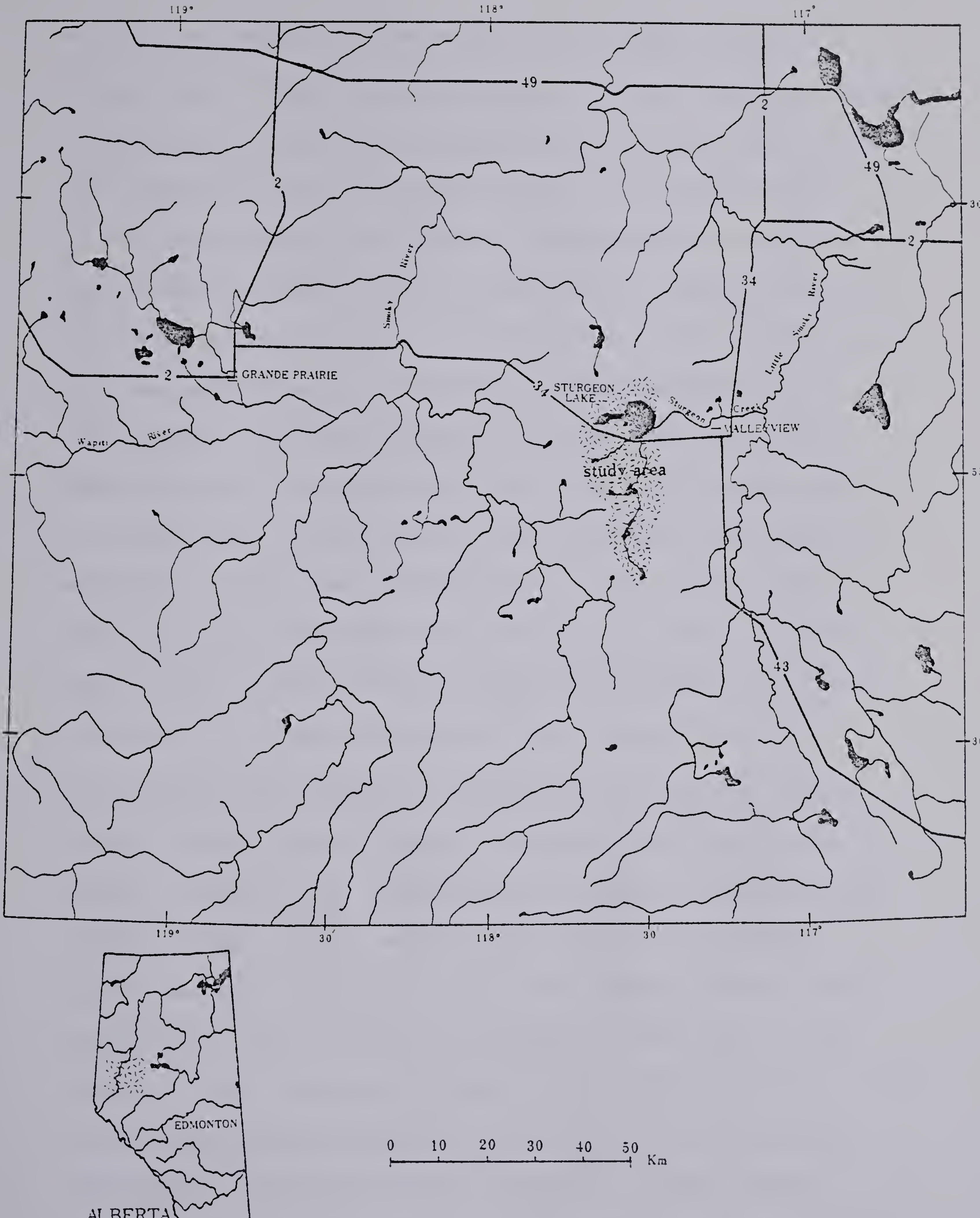


FIGURE 1 LOCATION OF STUDY AREA

Source: Atlas of Alberta, 1969

various disturbances and changes that are continually occurring.

In the course of time, man appeared on the shores of the lake. First, the earliest hunting nomads followed the animals they hunted to the lake, camped for a time and then moved on. With the coming of Sir Alexander MacKenzie in 1792-1793 white men began to stay in the Peace country to trade for furs. Settlement in earnest in this area did not begin until the 1900's. The first settlements, such as Calais which was established by 1910, were built near missions and fur trading posts. With the opening of the Edson Trail from Edson to Grande Prairie via Sturgeon Lake in 1911, the first steady trickle of settlers came into the basin. A small settlement was started at Valleyview in 1914 (Jones, 1966; Odynsky, et.al., 1956). As transportation systems improved, more and more people came to the area, first to hunt and trade, then as farmers and foresters, and finally as oilmen or to indulge in recreation and leisure activities.

The extending of the Edmonton, Dunvegan and B.C. Railway (now the Northern Alberta Railway Company) running along the south shore of Lesser Slave Lake, first to High Prairie in 1914 and then to Grande Prairie in 1918, brought about the first major influx of Peace country settlers. A graded dirt road was completed between Grande Prairie and Calais in 1929 and was extended beyond Calais to High Prairie in 1933. Growth was further accelerated with the construction of the Alaska Highway during World War II and then of the postwar 'Whitecourt - Valleyview cutoff', highway 43. It was highway 43 which allowed homesteaders and settlers to reach the Sturgeon Lake area with relative ease (Welmon, 1965).

1.3 LAKE MANAGEMENT AND THE CONCEPT OF ECOSYSTEM RESILIENCE

Long before man appeared on the scene, natural systems were subjected to sudden and sometimes catastrophic changes imposed by climatic variations and other geophysical processes (eg. the ice age). Small incremental changes to an environment, whether by man-made or natural causes, are usually absorbed by an ecosystem and do not generate immediate signals of their effects. However, the accumulation of changes or a massive shock may surpass the threshold level of an ecosystem, generating sudden and dramatic signals. The ecological systems that have survived over long periods of time are those that have been able to absorb and adapt to disturbances via some considerable internal resilience within the bounds of which change is acceptable (Hollings & Goldberg, 1971). Yet, as man has only recently become aware, however broad the domain of ecosystem stability may seem, it is not infinite.

When man first came to North America, the land was so huge and empty of humans that it was easy for nature to purify itself. With the appearance of white man, technology and new standards of living, it became difficult and then impossible for nature to assimilate the pollutants released to the air, land and water. In time, man came to see what was happening to the environment and began to try to find ways of dealing with it without giving up the style of life that first caused it. This requires vast amounts of new knowledge about how nature's systems work and what may be done to help or change the systems so that the environment remains healthy and diverse while also benefitting man.

CHAPTER 2

METHODOLOGY AND PROCEDURES

2.1 INTRODUCTION

In attempting to plan for a particular resource, one must consider how that part of an ecosystem affects and is affected by other parts of the same ecosystem. In this case, the resource under study is the lake. The major emphasis of the study is upon how the waters of the lake are affected by different types and methods of land use in the drainage area and possible means of ameliorating those effects. Other factors such as vegetation, soils, and so on, are also examined for possible contributions to changes in water quality. In order that this information may then be used by planners who are concerned with the whole picture, we must also consider how changes to the lake waters will affect the uses made of the lake. This analysis of interrelationships leading to change is the basis of the study.

The first step is to gather and present all of the relevant data about the study area so that the framework within which the study is to be conducted is outlined. For the purposes of this work, basic information about the physical parameters of the area which would affect the movement of nutrients and sediments from the land to the water were needed. The parameters which were chosen as being relevant were: lake physiography, bedrock geology, surficial materials and soils, topography, climate, vegetation, water balance, wildlife and waterfowl, fish and land uses. The data collected regarding these topics is presented in Chapter 3, Study Area.

As has been pointed out in section 1.3, natural ecosystems are

highly complex even before man initiates changes to the systems. While man's knowledge of the way in which the systems work and how changes will affect them is minimal in terms of the whole, it is important that we gather together as much of the available knowledge as possible as a basis for further study. Chapter 4 of this study is a summary of the data collected as Background Information, and examines some of what is known about the cycles of various nutrients in lakes, possible sources of them and their effects on lakes; potential sediment sources and their effects; the various parameters which are used to test water quality, what they indicate and suggested limits; and the expected naturally and culturally caused variations in tested concentrations of nutrients and sediments. It is intended that this chapter be in as simplified a form as is reasonably possible, to allow readers without a strong background in limnology, chemistry or biology to be able to grasp the concepts and problems inherent in this kind of study.

The results of the field work season are then presented in Chapter 5, along with an interpretation of what these observations indicate.

A discussion of the implications of the results and recommendations both for planning for this particular lake and for further study of the topic in general are presented in Chapter 6.

The Appendices include the tabulated results of the water balance calculations, stream flow records, tables of climatic records for the Grande Prairie weather station, a table of the recommended water quality criteria limits, tables and graphs showing the results of the water quality tests conducted on the waters of Sturgeon Lake

during the field season and a list of definitions of some of the scientific terms used in this study.

As the data used in this study are highly variable in type and character, the means of collecting and analyzing the data were also necessarily highly varied.

2.2 LITERATURE REVIEW

There have been at least thirty studies done which were directly concerned with Sturgeon Lake. Copies of these studies were obtained and data gathered from them were compiled and compared with data obtained during the field season to provide as accurate a description of the drainage basin as is currently possible. Comparison of data obtained previously with data obtained in 1978 gave an indication of trends of change over time.

The use of remotely sensed imagery for lake studies is a relatively new method of collecting data. Although it cannot reasonably be utilized without some ground work to correlate with the imagery, it can be very useful for filling some of the data gaps. There is a great deal of work going on to find out how the imagery can best be used. A number of papers documenting the results of some of this work were obtained and studied to find out if and how I could utilize the imagery in this study.

The number of reports available on the more generalized aspects of the study are, apparently, almost infinite. After reviewing almost 200 reports, it was acknowledged that comprehensive coverage would be impossible. The data which has been collected thus far were broken down into subject areas and written up as Chapter 4, Background

Information.

2.3 AIR PHOTOS

Aerial photographs of the drainage basin taken over a period of sixteen years were obtained and analyzed prior to the field season to obtain descriptive data for use in the preparation of field maps. The scales and dates of the photos used were: 1:40,000, 1950; 1:15,840, 1950-51, 1952, 1954-56; and 1:31,680, 1955-57, 1956, 1961, 1966. Infrared photos taken of the northern half of the lake basin in 1977 at a scale of 1:50,000 were located after the field work was complete and were used to cross check the updating of the maps which was achieved primarily through ground truthing.

The time spread of the air photos enabled me to study land use trends. Use of the air photos also helped in the establishment of drainage basin subdivision.

2.4 FIELD MAPS

Six field maps were drawn prior to the field season for use in establishing how the drainage area was to be subdivided and in the selection of water quality sample sites. These maps were drawn from air photos and published maps, ground truthed for accuracy and updating, utilized for basin subdivision and then some of the maps were modified to be included in this thesis. The maps which are included may be found in Chapter 3 in the selections related to each of them.

Drainage patterns were established from air photos and a published map. This aspect of study was strongly weighted in determining the basin subdivision as it helped in the identification of clear sampling points.

Land uses were ascertained from air photos and field checked to update the information obtained. In establishing the basin subdivisions, greater emphasis was placed on land uses close to the lake, partially due to the greater amount of use by man close to the lake and partially due to the probability that a greater portion of the water quality parameter concentrations are attributable to the more immediate causitive factors.

The vegetation map was drawn solely from air photos and then field checked and corrected. The categories used to describe the types of vegetative cover are intentionally broad, being used mainly to indicate the amount of ground cover present and the amounts and types of organic matter provided to the soil.

Both air photos and a published map (Odynsky, et.al., 1956) were used in the preparation of the soils map. Field checking for soil condition was conducted only along parts of the lake shore from which direct runoff would be generated close to a sampling site.

The topographic slope map was taken from a published source (Department of Mines and Technical Surveys) to correlate with the other maps in establishing the basin subdivisions. It was found that this map was not very useful as the slopes in the study area are all gentle on a 50 ft. contour interval. A slope map with a smaller contour interval would have been difficult to use in conjunction with the relatively large scale of the rest of the data.

A rough map of potential access routes (i.e. cut lines, oil company roads, old trails, et cetera) to various parts of the drainage area was drawn from the air photos. This was thought to be important as a

large part of the area is inaccessible by road. Unfortunately, most of the area proved to be inaccessible during the summer months anyway. The cut lines and old trails are largely grown in and are covered with bush and undergrowth which is up to six feet in height. The ground in much of the basin may be classed as 'forested muskeg' and is so wet and soft that it was unsafe to travel alone in the back country.

2.5 CLIMATIC DATA

Climatic records for Grande Prairie, High Prairie, Valleyview, Puskwaskau Lookout and Snuff Mountain Lookout were obtained from the Atmospheric Environment Service and from the individual stations. Temperature, precipitation, wind and frost records for the thirty year normal (1941-1970) were compared and correlated with the monthly records for 1969-1978 to establish the climatic trend and to determine whether the field season was close to normal climatically. The data were also used to estimate the climatic normal at Sturgeon Lake.

As all of the stations except Grande Prairie had periods of incomplete data in their records, the climatic data reported and used in all of the water balance calculations were based on the Grande Prairie data.

2.6 WATER BALANCE

The water balance for the Sturgeon Lake drainage basin was calculated according to Thornthwaite's empirical methodology as published in 1948. Calculations were made on monthly records for each year from 1969 to 1978 and on the 1941-70 normal. By doing the calculations for this time span, it was possible to determine how the 1978 field season water balance compared with the long term conditions.

The water balance was then adjusted to better represent the local conditions. The procedure for obtaining the water balance according to Thornthwaite as well as the assumptions made and reasons for the adjustments to the balance are fully discussed in section 3.7.

Streamflow data were obtained in Goose Creek and Sturgeon Creek by using a Moulinet Current Meter in stream cross-section segments with stream stage indicators attached to bridges in the creeks. Two smaller creeks, Pelican and Unnamed, were measured with the current meter at culverts passing under highway 34. Unfortunately, most of the data obtained in this manner proved to be of little use as the stream velocities were so low for most of the season that the readings on the current meter were unreliable. The data obtained for Sturgeon Creek were used to compare with streamflow data for a gauged stream outside the basin. Automatically recorded streamflow data for Spring Creek basin, which is just to the west of the Sturgeon Lake basin, were obtained for 1969-78 and used to cross-check the water balance calculations.

2.7 REMOTE SENSING IMAGERY

Five remotely sensed images of the Sturgeon Lake drainage basin were obtained and studied to establish whether or not it was feasible to utilize this data source. I determined that the mapping of turbidity patterns from remote sensing imagery was the best method available to me for indicating currents near the surface of the lake and their relationship to the water sampling sites. I also decided to attempt to use the imagery to correlate with the spot sampled turbidity measurements and obtain turbidity values for the whole lake. The

imagery was also used to map open water areas within the drainage basin.

The imagery which were utilized were: June 7, 1977 - band 4; June 7, 1977 - band 6; August 16, 1977 - band 4; July 25, 1978 - band 5; and August 8, 1978 - band 5. The last two imagery dates were also ground sampling dates thereby providing ground truthing to correlate with the imagery.

Study of the imagery was done at the Alberta Remote Sensing Center and most of the work was done using the microdensitometer there.

2.8 SAMPLE SITES

The sites at which water samples were taken were chosen to represent water quality conditions which probably related to the characteristics of the land near each site. Some of the sites were chosen due to the proximity of possible pollution inflows and some were chosen to obtain good distribution over the entire lake to faciliate the evaluation of overall water quality.

The first step in locating the water sample sites was to classify and divide the land surface into areas of similar environment. The land characteristics which were classified included vegetation, soils, slope, drainage and land use. The large study area compared to the micro scale of water quality differences required that the field maps not be too detailed so local variations were not mapped.

The drainage network and land uses were the main aspects of the basin which were used in establishing the subdivision of the basin. Stream inflows to the lake provide good sampling sites, with various water quality parameters being concentrated to a higher degree. This is

important because, although the basis of the study is in micro-quality differences, they must be detectable and significantly different. The quality variations were then attributed partially to the major land uses in the area drained by the creek. The land uses are paramount as the aim of the study is to relate them to water quality. The land use categories used were: agricultural, cottage use, intensive public recreation, extensive public recreation, oil and gas development, permanent residences, undeveloped muskeg areas and undeveloped well drained areas. Wherever possible these uses were assigned to two different sample sites, each exhibiting different site conditions, in order to get an indication of how natural site variations will affect the anthropogenic variations.

The vegetative cover, soils and slope of the land in each section of the subdivided basin were examined. While these factors were not highly influential in determining how the basin was subdivided, their potential influences on the water at the sample sites were considered in the analysis of the water quality tests.

Figure 2 depicts the basin subdivision and the locations of the water sampling sites. Each sample site was identified by sighting on prominent land features so that the exact location could be resampled on subsequent dates.

2.9 WATER QUALITY TESTS

Water samples were collected at ten or eleven sites (site 11 was added later on in the summer) at one week intervals. The collection days were usually on a weekend. The greater use of recreational and cottage sites on the weekends made the likelihood of obtaining

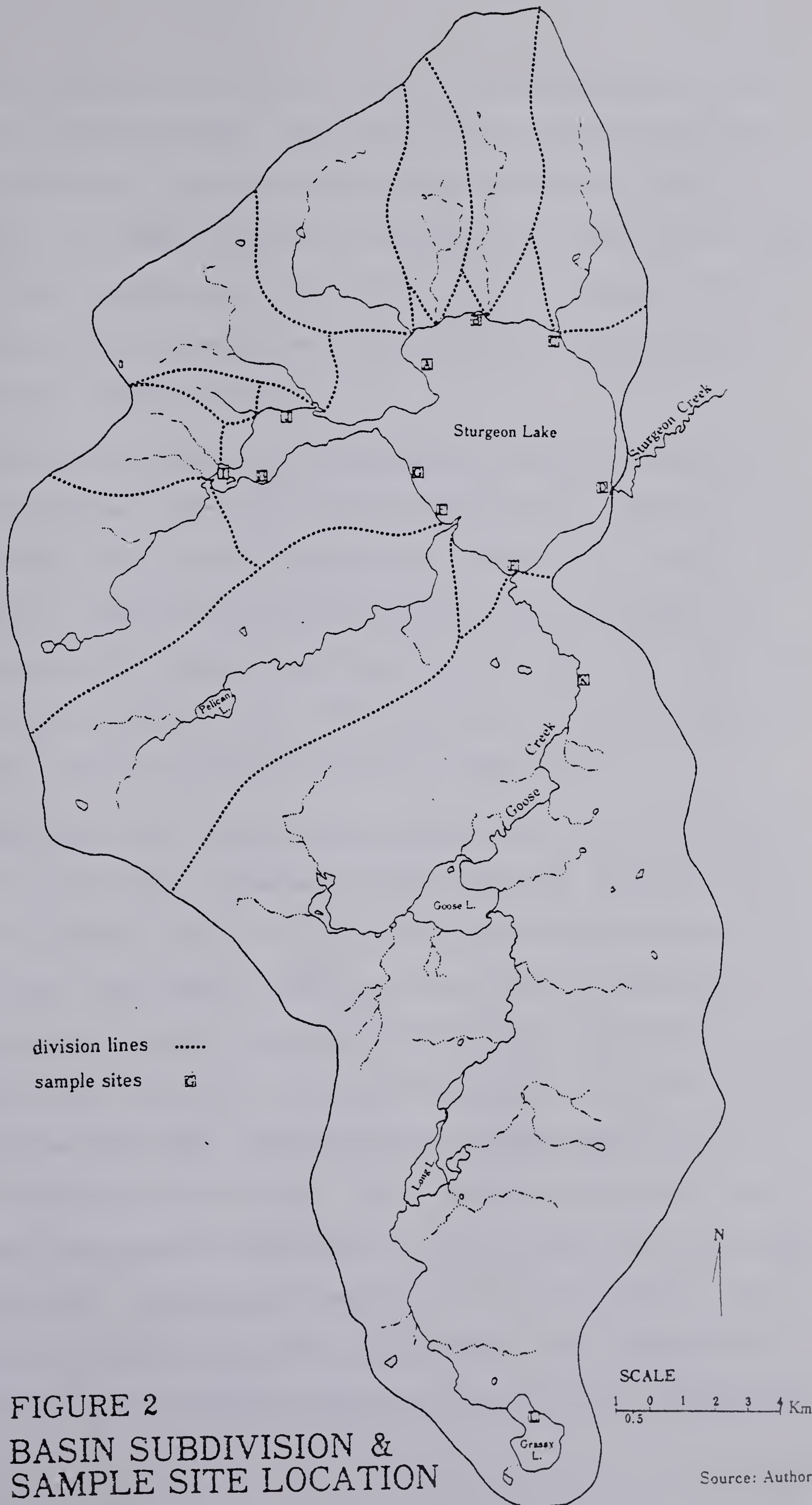


FIGURE 2

BASIN SUBDIVISION & SAMPLE SITE LOCATION

detectable differences in water quality due to recreational use of the lake resources higher. Also, the lake is often very rough and it was safer to go out in the boat when there were more people in the area. The sample intervals were changed only when weather conditions made it impossible to go out on the lake, or when an attempt was being made to coincide the collection of the samples with the passage of a Landsat Satellite.

The boat which was used most of the time for sample collection was a 12 foot aluminum craft with a 9.5 horsepower Evinrude motor. It took about eight hours in good conditions to collect all ten samples from this boat. When lake conditions were bad but not impossible, the Fish and Wildlife Officers made their 16 foot craft with a 100 horsepower motor available to me. With the help of the officer driving the boat, sample collections took two to three hours.

At each sample site, the boat was anchored at the 1 to 1.5 m depth, about 5 m from shore. Samples were collected with a Kemmerer Water Sampler from just below the surface to avoid contamination from the boat motor. Conditions at each sample site, such as wave height and wind speed estimations; wind direction; whether it was sunny or cloudy; aquatic vegetation amounts, types and conditions; and numbers of boats in the area were noted. Wind direction was determined by use of a small flag and a Silva compass. Water temperature was taken with an EIL temperature-oxygen depth probe at .3 m intervals from the surface to the bottom. As the oxygen segment of the depth probe was not functioning properly, dissolved oxygen samples were collected and stabilized using the Winkler Method for testing later. A secchi disc

reading was taken on the sunny side of the boat. One 1.25 litre plastic bottle was filled at each sample site for field tests and two 1.25 litre plastic bottles were filled from the sites chosen for lab analysis. A sample from each site was tested with a Beckman conductivity meter.

Samples from five of the sites were collected each time for lab analysis. Three of the sites chosen were changed each week so that a different group of five was fully analyzed periodically. The sites at the Goose Creek inflow and the Sturgeon Creek outflow were tested every time. By changing the groups of samples each time, it was possible to see the results for each site in relation to every other site at some point in time. It was not possible to test all of the sample sites every week due to budget restraints.

The lab samples were packed in specially constructed boxes and shipped on the first available bus to Edmonton. While these samples were not packed in ice, the boxes were designed to insulate the samples against temperature changes. A notice on the boxes stating that they were perishable samples asked that the University of Alberta Zoology Lab be phoned so that the samples could be picked up as soon as possible. The samples were then refrigerated until they could be tested. The bottles were cleaned, acid rinsed and returned by bus for further samples.

The lab samples were tested for: total phosphate, ortho phosphate, meta and poly phosphate, organic phosphate, silica, total Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, organic nitrogen, total hardness as calcium carbonate, pH, total alkalinity as calcium

carbonate, conductance, total residue, chloride, color, turbidity, sulfate, sodium and potassium.

The samples for field testing were transported to my summer accomodation and refrigerated overnight. In addition to the tests in the boat for conductance, temperature and secchi disc, the samples were tested with a Hach kit for iron, color, turbidity and pH. The dissolved oxygen samples were divided into three portions and at least two portions for each site were titrated according to the Winkler Method. One litre of water from each site was run through a Gelman filtering appartus using Whatman .5 mm glass fibre filters and frozen with magnesium carbonate powder for later analysis of chlorophyll a content. A Little Giant Vacuum Pump aided in accelerating the filtering process but as the summer algae blooms became thicker, some of the samples took over 18 hours to filter, even using two filters, one after the other. The chlorophyll a samples were tested in the Alberta Environment water quality lab in the fall of 1978. A Turner flourometer was used, making it possible to take readings of both chlorophyll a and phaeophytin a.

2.10 OTHER FIELD WORK

As much of the back country was examined as time and access allowed. Oil company roads provided good access to the area north and east of the lake. A small trail bike was used on some of the cutlines but usually the vegetation was too thick and the ground too soft to use the bike. Quite a large area was covered by hiking but soft ground and thick undergrowth also made this difficult. Observations of the north and south ends of the area were made with binoculars from the

PHOTO 2: TRAIL BIKE ON CUTLINE NEAR SAMPLE SITE L

The handlebar of the trail bike is about a meter above the ground. This degree of cutline regrowth made back-country travel very difficult, especially since the ground was very wet.

forestry lookout towers.

Several of the creeks entering the lake were followed upstream for a distance. Observations of flow conditions and erosion hazard were made.

Grassy Lake and Pelican Lake were reached by hiking as close to open water as the swampy terrain allowed. Water samples were collected from these two lakes to use as indicators of upstream water quality. Due to the difficulty in reaching these sites, only spot samples were obtained and it must be taken into consideration that these are probably not representative of the whole of each lake.

Temperature profiles were taken at three locations on Sturgeon Lake to a depth of 6.5 m with the EIL temperature-oxygen probe.

Informal interviews with area residents and lake users were conducted whenever the opportunity arose. While this is certainly a haphazard approach to interviewing it yielded some interesting insights into how the people closest to the lake view changes in its condition and uses.

CHAPTER 3

STUDY AREA

3.1 LOCATION AND GENERAL INFORMATION

Sturgeon Lake is approximately 365 road km north west of Edmonton at latitude 56 07'N and longitude 118 35'W. It lies in townships 70 and 71, ranges 23 and 24, west of the fifth meridian. The lake drains via Sturgeon Creek, which is the only outlet for the lake and is controlled by a dam, into the Little Smoky River. This then joins the Smoky River and flows into the Peace River (see figure 1).

The total area of the Sturgeon Lake drainage basin is some 620 sq km and, with a lake surface area of approximately 38.8 sq km at crest level, a net drainage area of about 581.2 sq km. The water surface of Sturgeon Lake is at an elevation of 677 m A S L when it is level with the crest of the control structure. This lake level varies dramatically with the season and with climatic conditions, reaching the highest levels after spring runoff and the lowest levels in the late summer. Over six years of observation, a low level of 676.36 m and a high level of 677.62 m were recorded making a maximum variation of 1.26 m (Quaternary Geosciences Ltd., 1973, pg.39). Further details of lake morphometry are shown on table 1 and figure 3 is a representation of the bottom contours of the main body of Sturgeon Lake with the depth below the water surface marked in meters.

The 45.5 km of lakeshore are fairly regular with generally narrow beaches with marshy backshores and weedy offshores. Some shoreline areas have muskeg right up to the water's edge. Short stretches of narrow sand beaches are found at intervals around the lake. Some long

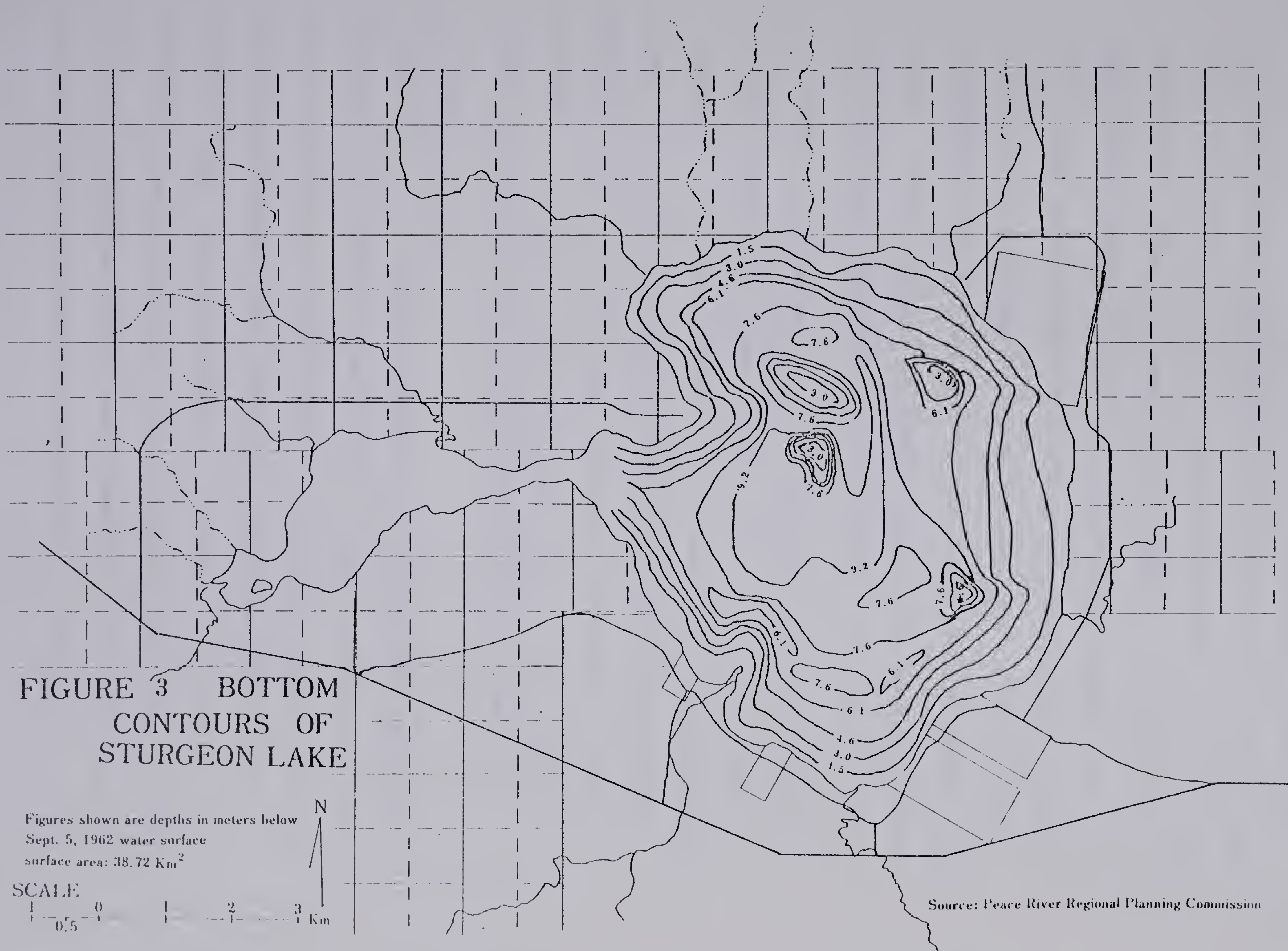


FIGURE 3 BOTTOM CONTOURS OF STURGEON LAKE

Figures shown are depths in meters below
Sept. 5, 1962 water surface
surface area: 38.72 Km^2

SCALE

Source: Peace River Regional Planning Commission

time residents of the area tell of wide sand beaches running all around the lake when water levels were allowed to drop in late summer before the control structure was built on Sturgeon Creek (pers. comm. with Mrs. Fred Young who homesteaded on land that is now part of Young's Point Provincial Park, and with Mr. Babe Bazerab of Calais, 1978). Sand has been found to be the predominant bottom material to the two meter depth along the shore (Bishop, 1977). The shoreline and bottom materials in the western arm of the lake are largely organic detritus. Bottom deposits of organic detritus and mud also predominate in the deeper sections of the lake (Bishop, 1977; Bishop, 1971a).

The Sturgeon Lake drainage basin has many low lying areas which virtually always retain some moisture, thereby acting, at least seasonally, as internal storage basins. Many of the channels joining these depressions and muskegs are ephemeral, connecting the entire drainage network only when water levels are high enough to cause overflow. Therefore, the drainage basin is only at its fullest extent when there is above average precipitation or snowmelt.

3.2 BEDROCK GEOLOGY

Information on the bedrock formations is from published information, where data were obtained from oil and gas wells and from water well logs. The bedrock is of both marine and non-marine origins, with the near surface deposits being sandstones, shales and siltstones of Cretaceous age. These are underlain by Mesozoic rocks of similar lithologies, which are in turn underlain by Paleozoic rocks, primarily carbonates and shales. The basement bedrock is crystalline rock of Pre-Cambrian age (Quaternary Geosciences Ltd., 1973).

TABLE 1 STURGEON LAKE MORPHOMETRY (AT CREST LEVEL)

LAKE ELEVATION	677 m ASL
SURFACE AREA	38.8 km^2 (3880 ha)
VOLUME	2.17×10^7 m^3
MEAN DEPTH	5.6 m
MAXIMUM DEPTH	9.2 m
MAXIMUM LENGTH	13.7 km
MAXIMUM EFFECTIVE LENGTH	11.6 km
MAXIMUM WIDTH	9.2 km
MAXIMUM EFFECTIVE WIDTH	8.4 km
DIRECTION OF MAJOR AXIS	N 83 E
SHORE LENGTH	45.5 km
NET DRAINAGE AREA	581.2 km^2

sources: Peace River Regional Planning Commission, 1978, pg. 4; Quaternary Geosciences Ltd., 1973, pg. 38.

Sturgeon Lake is located on the east limb of the Alberta syncline and the strata dip at about half a meter per kilometer to the south west into the Alberta syncline, thickening in the same direction. The bedrock high in the drainage area is over 732 m ASL near Puskwaskau Forest Lookout Tower in the north end of the basin. There is an east-west trending low at less than 640 m in the vicinity of Sturgeon Lake. This bedrock low as well as one which trends south from Sturgeon Lake are probably buried bedrock channels. However, there is not yet enough geologic evidence to conclusively establish the presence of

granular fill in these bedrock lows (Quaternary Geosciences Ltd, 1973).

The near surface bedrock, the Wapiti Formation, caps the upland near Sturgeon Heights where it averages 3 to 6 m in thickness. It averages 349 m in thickness in the Young's Point Park area and about 91 to 122 m near Valleyview, with units of up to 1220 m having been located near the study area within the Peace Region. It is usually overlain by a mantle of glacial and post-glacial deposits. These Upper Cretaceous sequences (Wapiti Formation) of non-marine sandstone and shale bedrock with some thin coal seams are soft and tend to slump easily. The upper surface is highly dissected due to erosion by pre-glacial rivers and tributaries flowing north east from the Rockies. The rivers eroded into the relatively soft bedrock resulting in low bedrock divides separated by a series of dendritic basins. The individual lithological units are gradational in character and commonly lense out within two or three kilometers from outcrop faces. The units vary in thickness from a few centimeters to over fifteen meters. All phases of the sandstone to shale gradation are common with occasional thin beds, never more than about half a meter, of freshwater limestone. Detrital materials within this formation are mainly fine crystalline rock fragments, largely of volcanic origin, with fragments of quartz, chert and feldspar. Many of the softer fragments have been crushed and squeezed into an interstitial clay matrix, filling some of the intergranular pore space. Some of the remaining pore spaces are partly or completely filled by fine crystalline authigenic clay cements which have been deposited from solutions subsequent to burial and compaction of the sandstones. These conditions combine to make the Wapiti Formation a fairly good source for groundwater (Quaternary Geosciences Ltd., 1973; Jones, 1966).

Underlying the Wapiti Formation is a sequence of marine shales and sandstones known as the Smoky River Group which are of Cretaceous age. Three formations of significance are found in the area: the Puskwaskau Formation of shales; the Bad Heart Formation of massive sandstones; and the Kaskapau Formation of thick shales. These formations are all too deep to serve as potential groundwater aquifers (Quaternary Geosciences Ltd., 1973; Jones, 1966).

3.3 SURFICIAL MATERIALS AND SOILS

Surficial deposit descriptions are from air photo interpretations and published data which included detailed field mapping and lab analysis of samples. Due to the Pleistocene glaciation, the bedrock in the drainage basin is mostly overlain by a mantle of glacial and post-glacial sediments (see figure 4) which average 30 to 45 m in thickness (Osamoa, 1978; Quaternary Geosciences Ltd., 1973; Boyacioglu, 1972). The continental ice sheet moved generally in a north-south direction in this area, and two till types indicate some ice frontal fluctuation or two distinct advances. The till deposits are generally thickest in the valleys and thinner on the uplands with some evidence of till-filled meltwater or pre-glacial channels near Sturgeon Lake (Jones, 1966; Odynsky, et.al., 1956). Glacial till is not often found on the surface in the drainage area, but underlies glacio-lacustrine sediments deposited when a pro-glacial lake was formed here during the Wisconsin period (Odynsky, et.al., 1956). Deep clay lacustrine beds consist primarily of rhythmically bedded silts and clays with some silty sand. This pattern is produced by continuous meltwater flows responding to seasonal fluctuations in melt and/or turbidity currents from an ice sheet melting into a pro-glacial lake. A high rock content in the

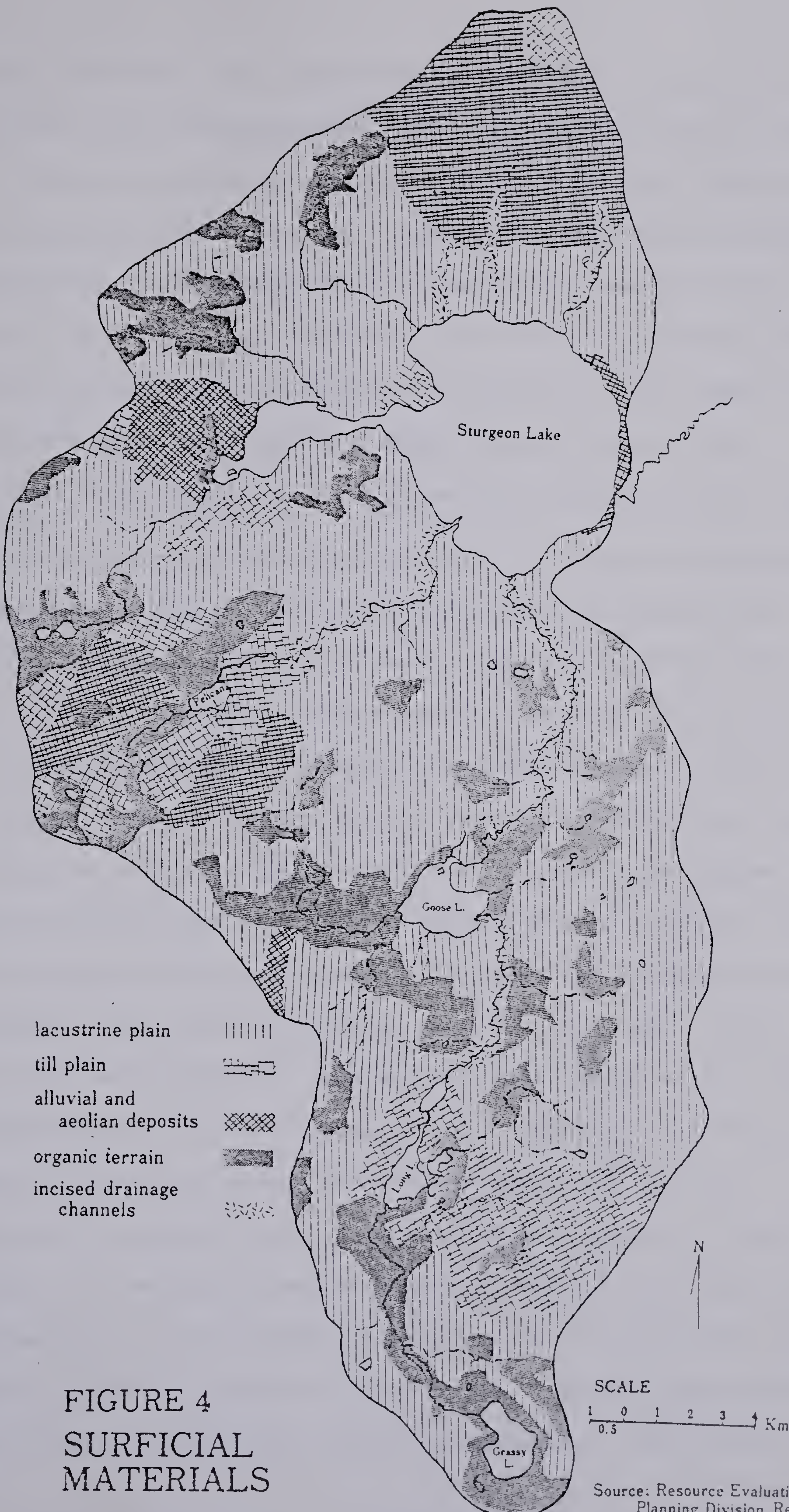


FIGURE 4
SURFICIAL
MATERIALS

Source: Resource Evaluation and Planning Division Reports

sediments, indicating that they were deposited close to a glacier, often gives them a till-like appearance. Much clay and silt with rock fragments, till balls and quartz grains are prominent in these sediments. Glacio-lacustrine sediments cover a large percentage of the drainage basin and reflect the general slope of the bedrock surface. Some localized reflection of ground moraine and hummocky moraine has relief of up to 10 m which is superimposed on the general slope. These relief features may also reflect eroded bedrock surface irregularities (Quaternary Geosciences Ltd., 1973; Jones, 1966; Odynsky, et.al., 1956).

The relatively flat to rolling glacio-lacustrine sediment topography has been somewhat modified by post-glacial erosion and deposition. The pattern of recent lacustrine, beach, alluvial and aeolian deposition is complex but most of the deposits in the area are found along present lake and stream shores (Quaternary Geosciences Ltd., 1973). Post-glacial erosional features such as gullies, creek valleys, scarps and slumps are also found mostly along the streams and lake shores. These post-glacial erosional features along with the outlets for lakes and sloughs and the drainage network are quite poorly developed since the regional post-glacial climate has been relatively dry. In the more recent, more humid past, some drainage development has taken place but stream dissection is still minimal. The steep banks with massive slumping in some areas reflect the incompetence of the surficial deposits and the bedrock strata. The many lakes, ponds and sloughs found here are remnants of the larger pro-glacial lake and reflect the low permeability of the surficial materials as well as the gentle slope. These waterbodies also serve to indicate that there is an approximate balance between precipitation and evapotranspiration. Small spring

surpluses in the water balance are maintained in surface dentention storage by local ponding. This is followed by in situ evaporation during the summer and fall deficit periods. This pattern varies annually as the water balance fluctuates with climatic conditions (see section 3.7 for more detail). Considerable sedimentation is slowly filling in these waterbodies (Greenlee, 1973; Quaternary Geosciences Ltd., 1973; Jones, 1966).

Much of the soil parent material in the study area appears to be of post-glacial origin with the glacio-lacustrine grey to dark grey heavy clays being found in many areas, particularly south and east of Sturgeon Lake (see figure 4). At elevations of over 700 m, the till plain remnants which are high in clay content provide the parent material for soils. The soils in the drainage basin are generally fine textured clay and clay loams with high contents of Montmorillonite clay (Odynsky, et.al., 1956). This gives the soils high shrink-swell potential and they are readily compactable and only slightly permeable to downward percolating water. As can be seen in figure 5, grey wooded soils are the most common with some brown wooded, degraded black, acid brown wooded, gleysolic and organic soils (Greenlee, 1973; Odynsky, et.al., 1956). Many of these soil types are potentially arable but, with the exception of the sandy or loamy soils, are poorly drained (Brocke, 1977).

Over 20% of the surficial deposits in the study area are muskegs with the exact value depending on the classification system used. No attempt has been made in this study to differentiate muskeg from other types of marsh due to the fact that the division between types of

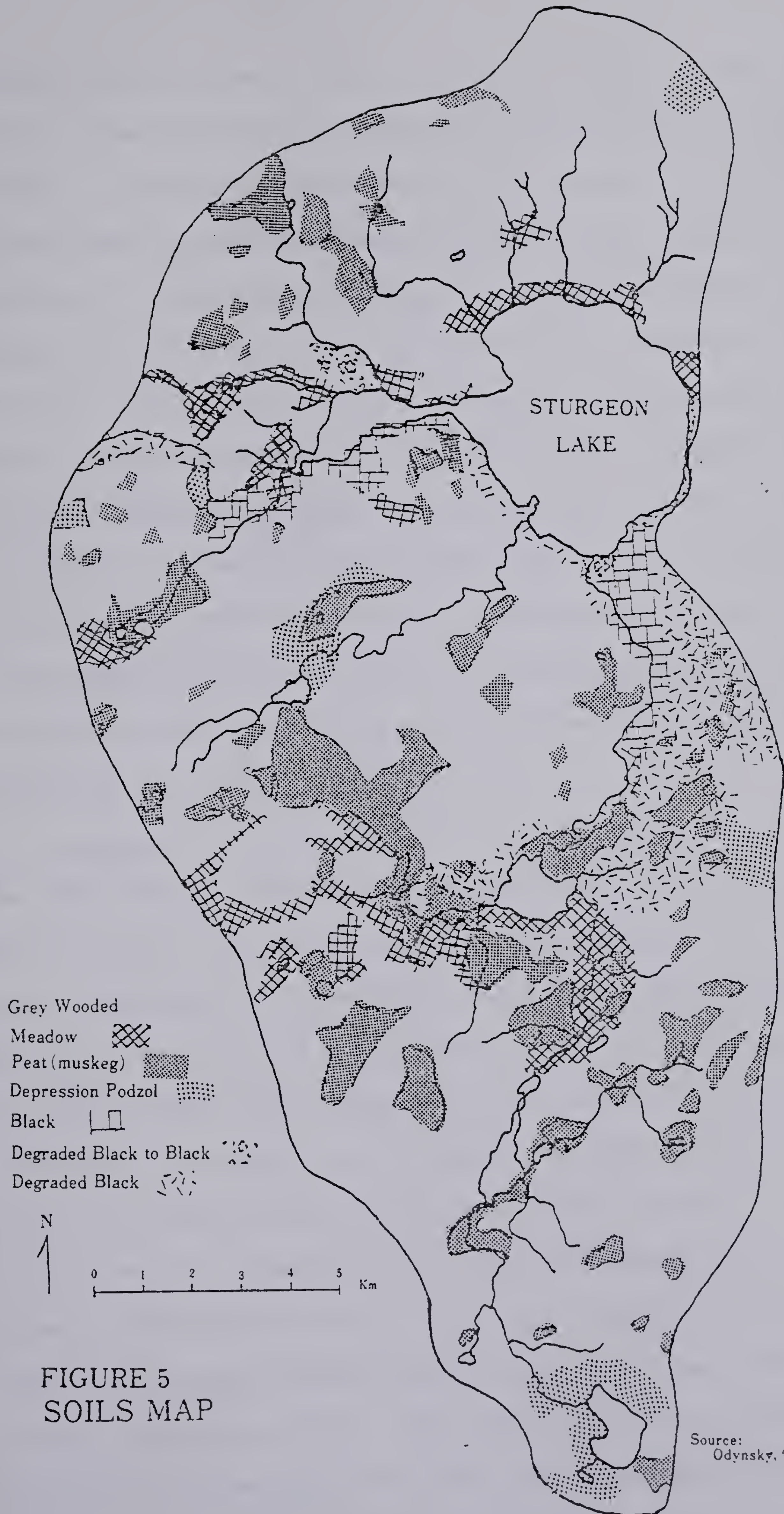


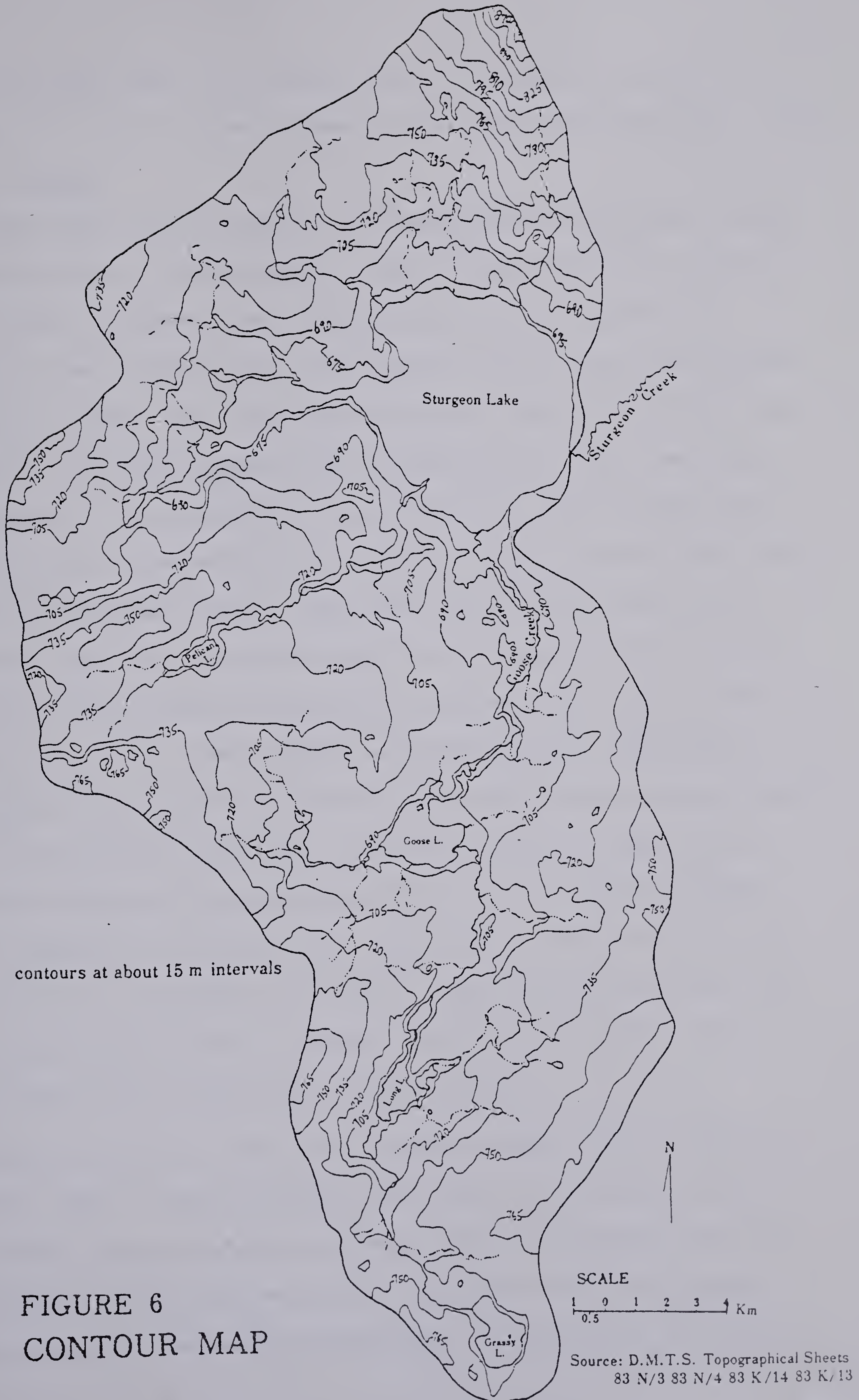
FIGURE 5
SOILS MAP

Source:
Odynsky, et. al., 1956

wetlands varies markedly from year to year as weather conditions change. These deposits are irregular in size and shape (see figure 4) forming in topographic depressions in the surface of the underlying glacio-lacustrine sediments where drainage is poor. The surface of the muskeg is composed of a living mat of mosses and grasses with Labrador tea present in almost all localities. Sparce tree cover is of willow, black spruce and birch and exhibits the stunted growth typical of muskeg environments. Subsurface muskeg material consists of highly compressible fibrous woody peat with occasional interbedded fine clays. The muskegs are sometimes flat but often they have small hummocks and ridges with less than .5 m of relief. A small percentage of the muskegs in this area are of the open pond types where standing water exists above the organic debris (Ojamoa, 1978; Quaternary Geosciences Ltd., 1973; Boyacioglu, 1972).

3.4 TOPOGRAPHY

The study area is situated on the extreme south fringe of the Peace River Lowland on the Wapiti Plain but exhibits much of the more varied topography of the south and east parts of the Alberta Plateau. The land is mostly level to undulating and is gently rolling west of the lake and where the remnants of the till plain are located north of the lake (see figure 6). The slopes from the till plain remnants to the low lying lake basin are generally long and fairly uniform, seldom exceeding a gradient of 6% (Quaternary Geosciences Ltd., 1973). The area around the west end of the lake is a bedrock high and is classified as gentle uplands with the associated broad, gently sloping prairies (Boyacioglu, 1972). The highest elevation in the study area is 884 m ASL to the north of the lake. The lake surface at about 677m



contours at about 15 m intervals

FIGURE 6
CONTOUR MAP

Source: D.M.T.S. Topographical Sheets
83 N/3 83 N/4 83 K/14 83 K/13

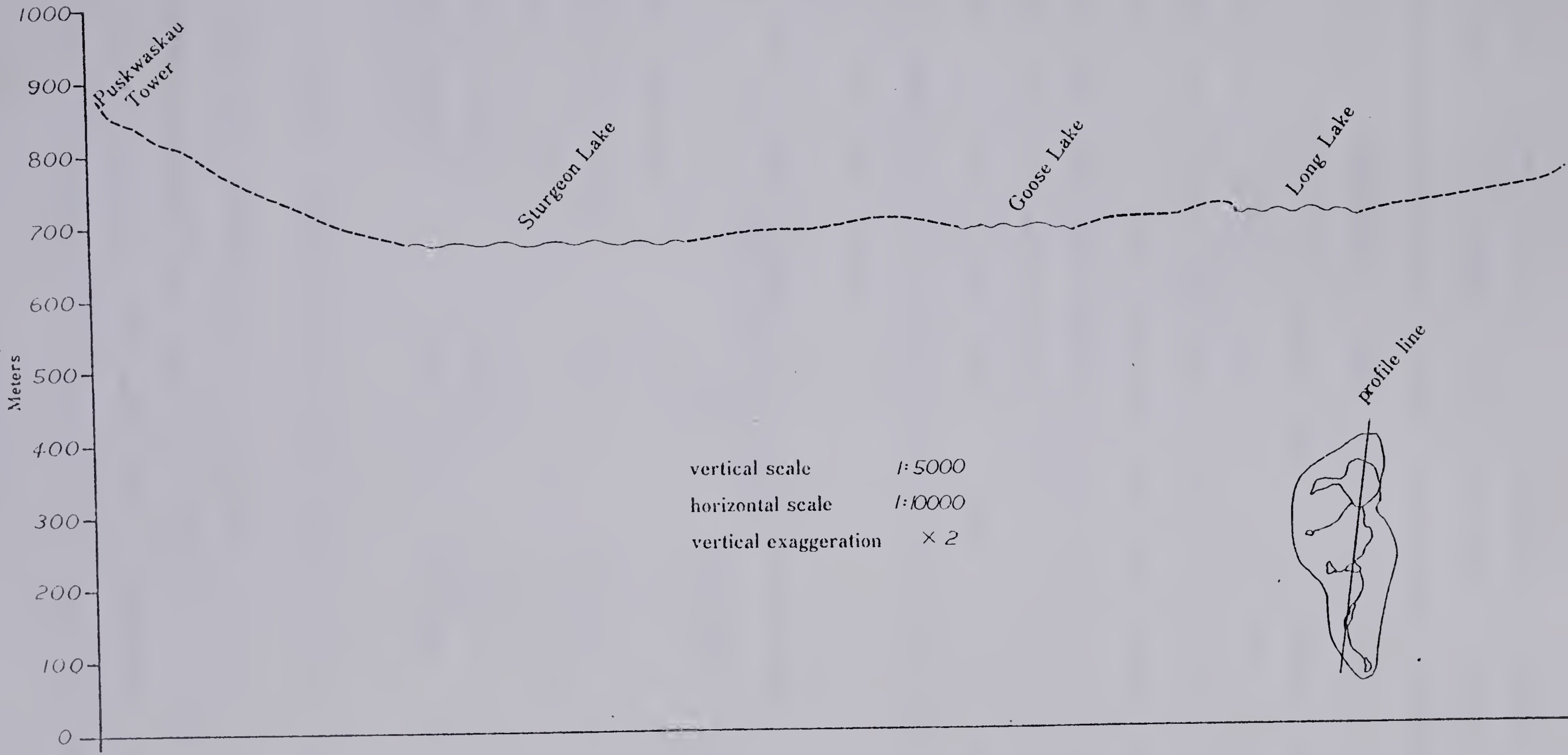
is the lowest point. The highest point of land in the southern end of the basin is at 777 m (see figure 7) (Quaternary Geosciences Ltd., 1973).

3.5 CLIMATE

Climatic data were obtained for the weather stations at Grande Prairie and High Prairie, each of which is approximately 80 km away from the study area. These data were compared with the more sporadic or seasonal data available for the stations at Valleyview, Snuff Mountain Forestry Lookout Tower and Puskwaskau Lookout Tower, all of which are close to the study area but cannot provide accurate long term annual averages. It was decided that since the Grande Prairie station was the one which provided the most consistent record, the data from there, with supplementary comments where applicable, would be used in this study. Long term averages are those for the 1941-70 'normal' period. Ten year averages were calculated by compiling annual data for the 1969-1978 period. Both averages were compared to the 1978 data to establish what the weather was like in the field season year as compared to normal weather conditions. The major factors for comparison for each of these three periods are shown in table 2. Monthly averages for temperature and precipitation over the long term and annually for 1969-1978 are presented in appendix 1. The data from the other four stations were used only to indicate how the climate in the Sturgeon Lake area may vary from that at Grande Prairie.

Sturgeon Lake is in a cool, dry, subhumid climatic region (Chapman & Brown, 1966). Climatic patterns are typical of the western prairie woodland transition areas with summers which are moderately warm and winters which are relatively cold. The temperatures are extremely variable daily, seasonally and annually. The snow cover in winter is

FIGURE 7 TOPOGRAPHIC PROFILE OF DRAINAGE BASIN



Source: Author

generally from November to mid-April and January is the coldest month. There are usually ten to fifteen chinooks each winter. Spring is a short season coming sometime between March and May and is characterized by a rapid rise in temperature. Summer is from about mid-May to mid-September with July being the warmest month. A short autumn falls between September and November (Martz, 1979; Longley, 1972; MacIver, 1966). The average annual temperature for both the long term and ten year period is 1.2°C. Figure 8 has been constructed to depict the mean annual temperatures from 1969-1978 in graph form while figure 9 is a graphic representation of the mean monthly temperatures for the same period. It can be seen that 1978 was warmer than usual, with a mean annual temperature of 1°C higher than the long term average (Atmospheric Environment Service, 1978).

TABLE 2 MAJOR CLIMATIC MEANS, GRANDE PRAIRIE DATA
(for three time periods)

	1978	1969-1978	1941-1970
MEAN ANNUAL TEMPERATURE	2.2°C	1.2°C	1.2°C
MEAN ANNUAL PRECIPITATION	332.7 mm	432.8 mm	442.0 mm
MEAN ANNUAL WIND VELOCITY	14.3 km h^{-1}	10.4 km h^{-1}	14.3 km h^{-1}
MEAN FROST FREE SEASON	118 days	99 days	92 days
MEAN ANNUAL POTENTIAL EVAPOTRANSPIRATION	526.1 mm	510.9 mm	515.6 mm

source: Atmospheric Environment Service, 1978 & 1975

Long term mean annual precipitation in the region is 442 mm. Mean monthly values for 1969-1978 are presented graphically in figure 10 and figure 11 is a depiction of the mean annual precipitation, broken down into snow and rainfall for the same period. From these graphs, it

FIGURE 8 MEAN ANNUAL TEMPERATURES 1969-1978

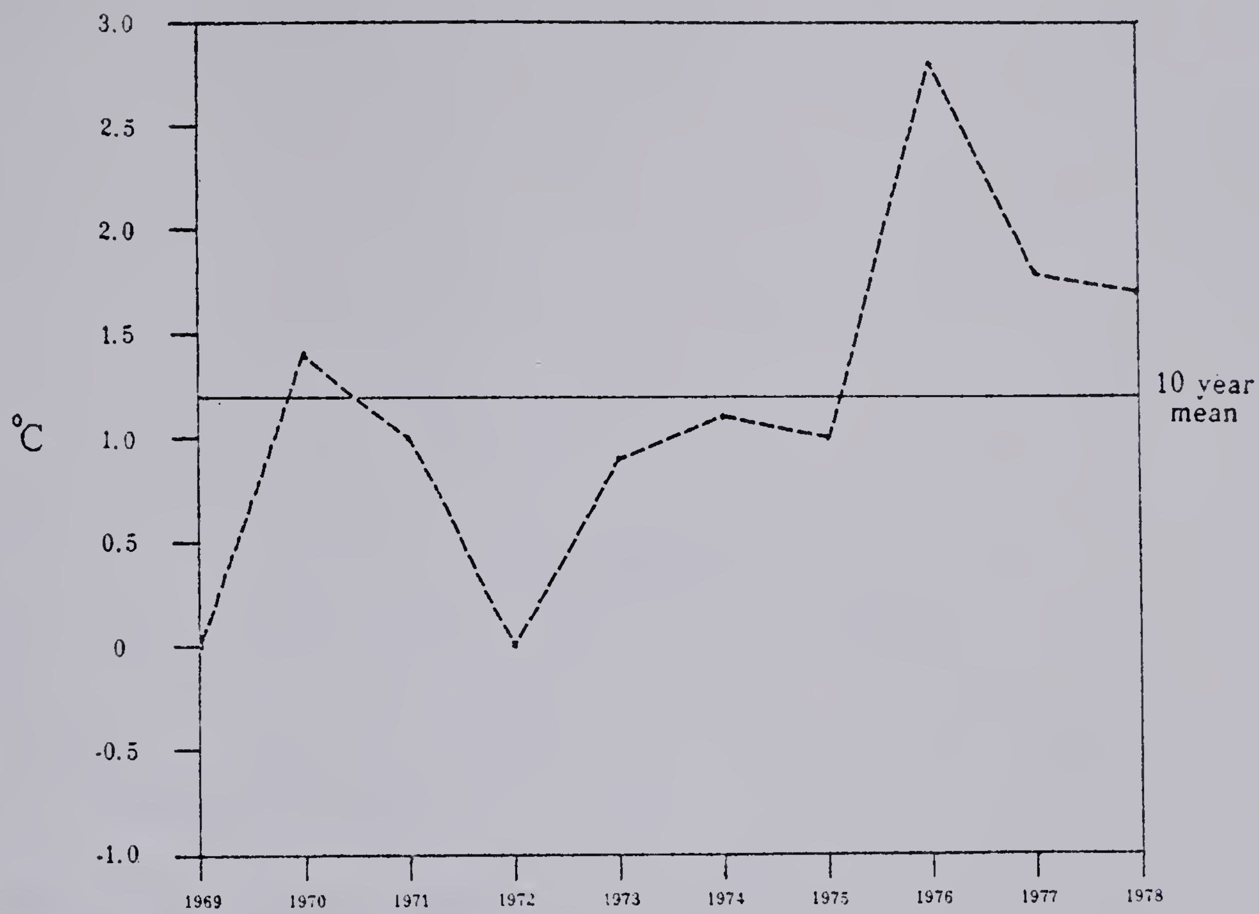
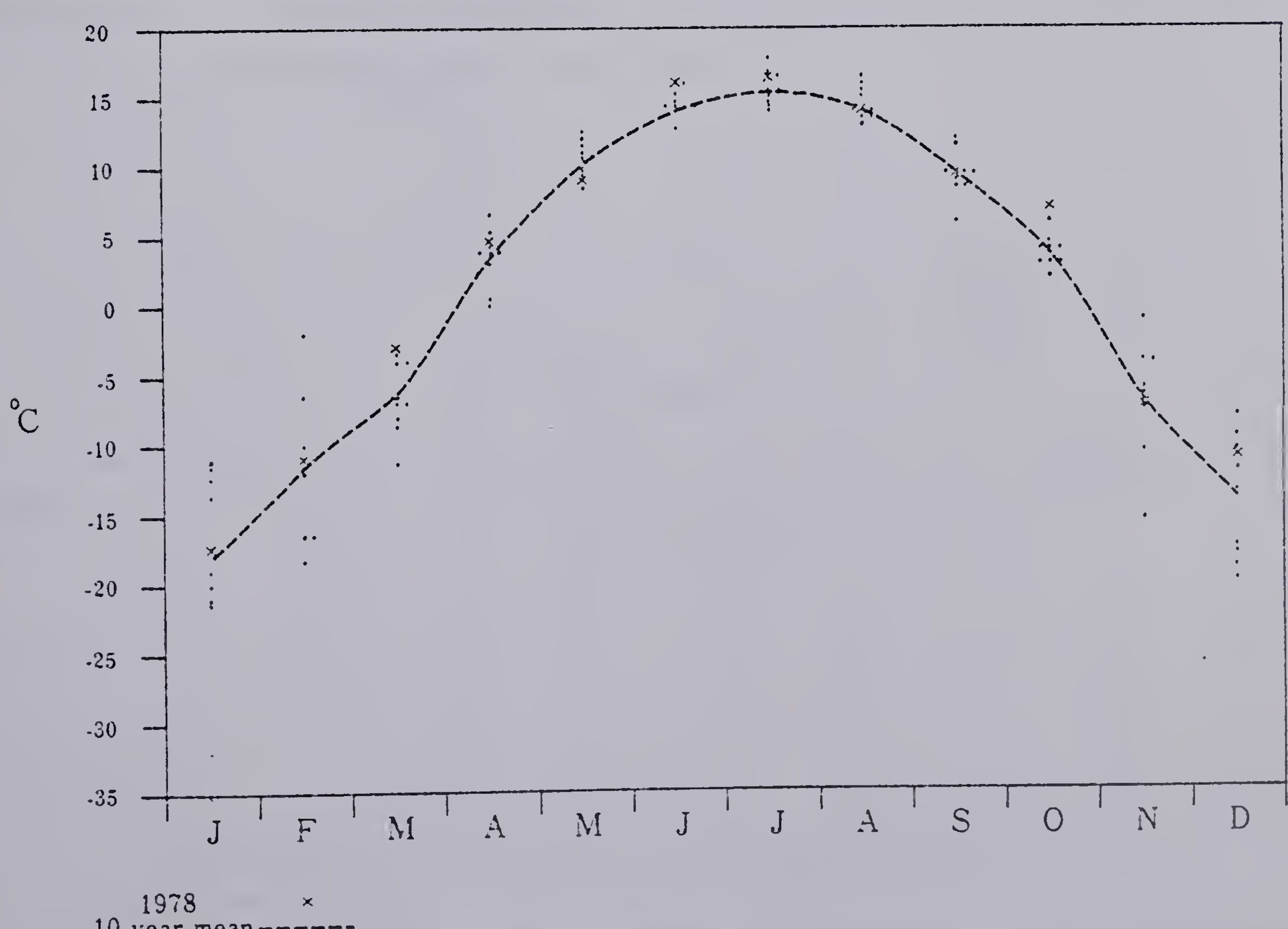


FIGURE 9 MEAN MONTHLY TEMPERATURES 1969-1978



Source: compiled from Atmospheric Environment Service Monthly Meteorological Reports

FIGURE 10 MEAN MONTHLY PRECIPITATION 1969-1978

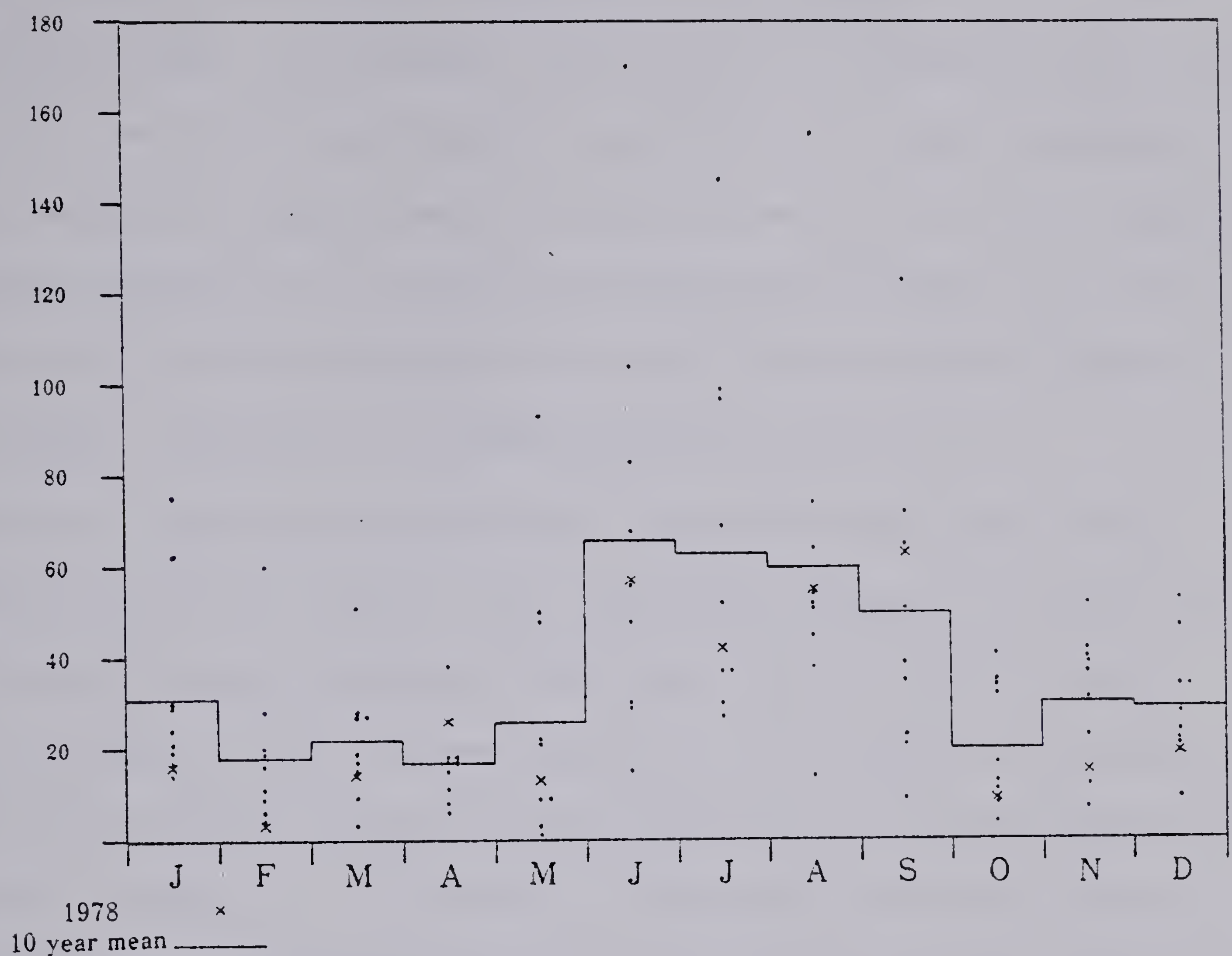
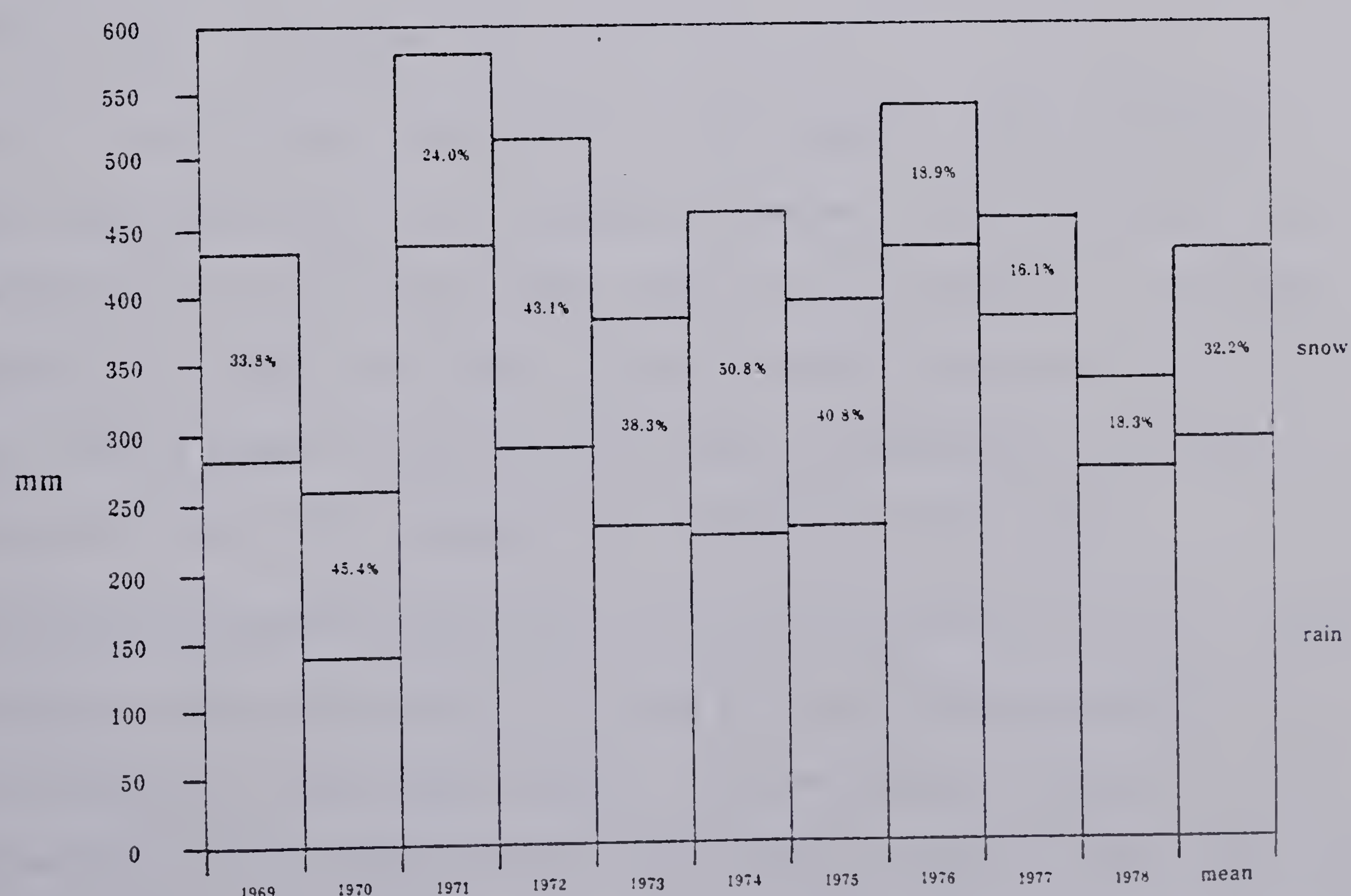


FIGURE 11 MEAN ANNUAL PRECIPITATION 1969-1978



Source: compiled from Atmospheric Environment Service Monthly Meteorological Reports

can be seen that 1978 had lower than average precipitation in every month but April and September. The percentage of precipitation falling as snow was also below average. Precipitation is usually moderate in all seasons with approximately 30% falling as snow. Over the long term, maximum snowfall is in January and maximum precipitation is in June. Some 56% of the annual precipitation falls between May and the end of September (Atmospheric Environment Service, 1978 & 1975).

Potential evapotranspiration (P.E.) calculations were done for the water balance (see section 3.7). Long term average P.E. was 515.6 mm while the ten year average was 510.9 mm. P.E. in 1978 was higher than average at 526.1 mm (see figure 12). The monthly P.E. patterns with the maximum, minimum and mean values over the ten year period are shown in figure 13. The 1978 P.E. values were at or above average in every active month except May and August. That is because May and August are the only summer months in which the mean monthly temperatures were below normal (see figure 9).

91% of the frost free days per year occur between April and October. The last spring frost can be expected sometime during the first three weeks of June and the first fall frost early in September. The mean frost free season of 92 days is highly variable from year to year so the 118 day season in 1978 was not unusual (Atmospheric Environment Service, 1978 & 1975; Longley, 1972; Chapman & Brown, 1966).

Relatively constant winds throughout the year average 17.5 km h^{-1} with average annual peak winds of 65-80 km h^{-1}, although measurements of over 112 km h^{-1} have been recorded. The percentage frequency of wind direction over the long term are out of the W. 25%, N.W. 17%, S.W. 12%, E. 10%, N.E. 9%, N. 9%, S. 6%, S.E. 5%, and it is calm 7% of the time

FIGURE 12 MEAN ANNUAL POTENTIAL EVAPOTRANSPIRATION 1969-1978

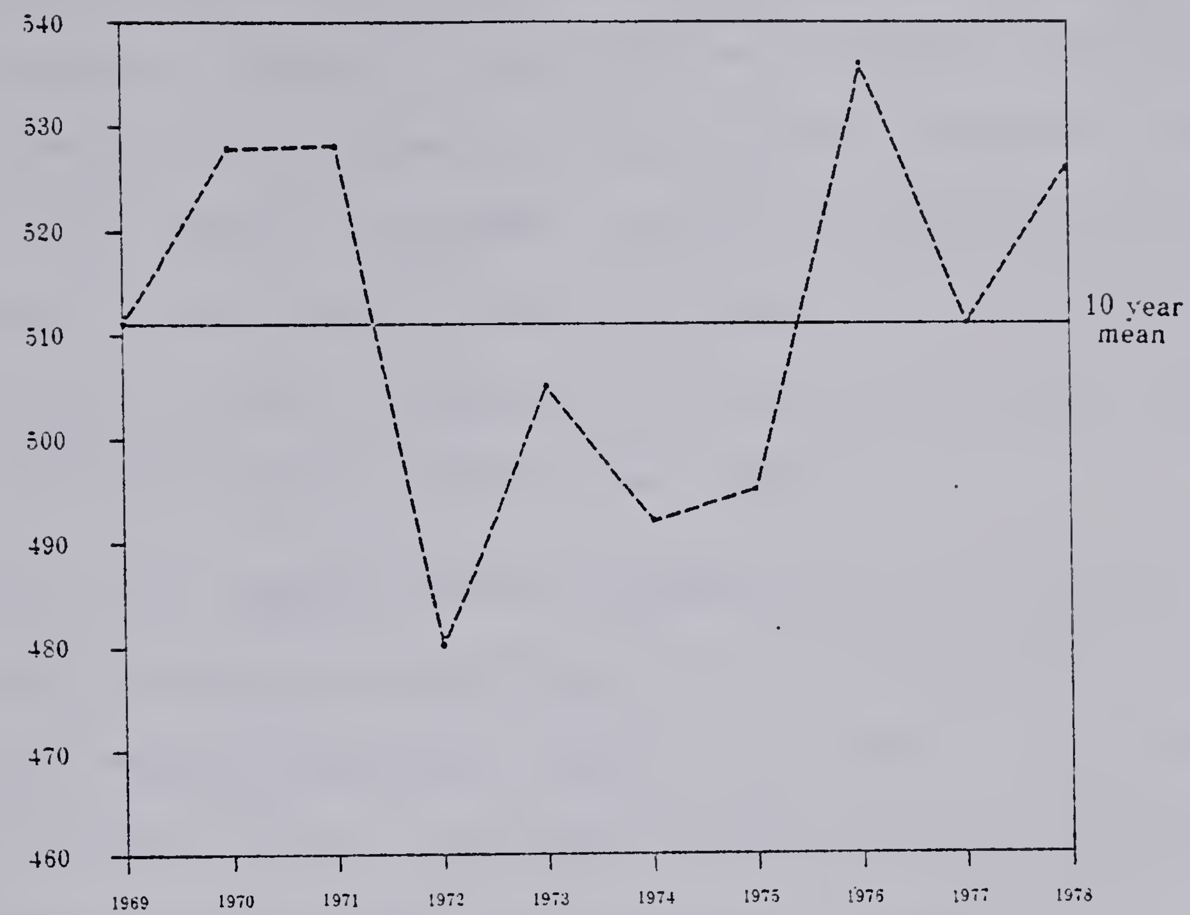
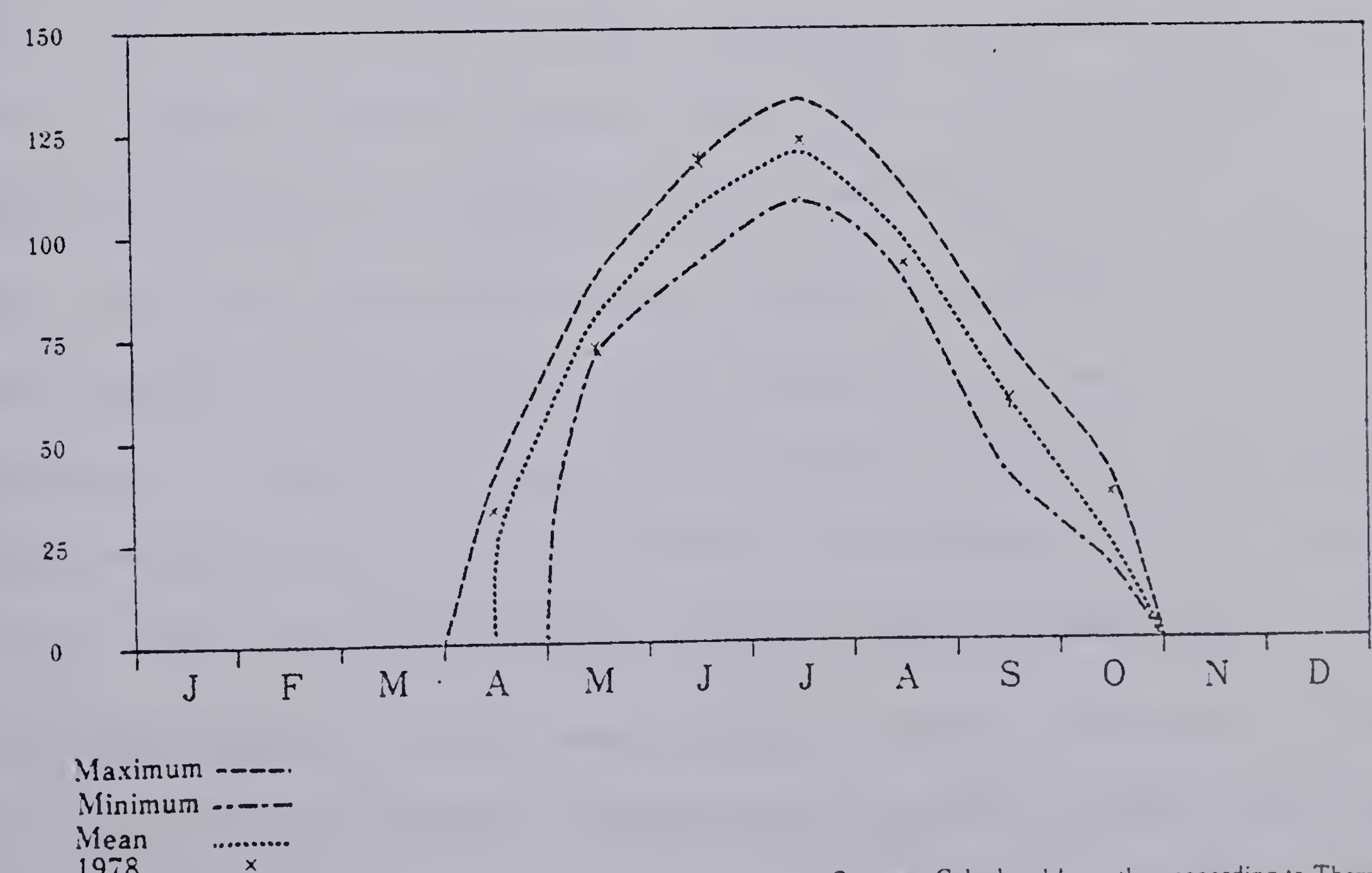


FIGURE 13 MEAN MONTHLY POTENTIAL EVAPOTRANSPIRATION 1969-1978



Source : Calculated by author according to Thornthwaite's procedures with data from the Atmospheric Environment Service

(Atmospheric Environment Service, 1975).

Storms occur throughout the year but vary in type and frequency. Spring storms are frequently severe with heavy snowfalls or thunderstorms. Isolated short showers or thunderstorms, sometimes associated with hail, are common in the summer. Most of the autumn precipitation is from well defined frontal storms with showers or thunderstorms. The major winter storms are blizzards or snowstorms (Longley, 1972; Quaternary Geosciences Ltd., 1973; Jones, 1966).

Comparison of the climatic data for Grande Prairie with the data for High Prairie, Valleyview, Snuff Mountain L.O. and Puskwaskau L.O. yields some general patterns of variation (see table 3). The elevation of Sturgeon Lake is 677 m. The Grande Prairie station is only 8 m lower than that at 669 m while the High Prairie station is 83 m lower at 594 m. The other three stations are all higher: Valleyview at 762 m is 85 m higher, Snuff Mountain is 292 m higher at 969 m and Puskwaskau Tower is 295 m higher at 972 m. It is important to keep in mind that it is the climate over the whole Sturgeon Lake basin that is important and not just the lake itself so elevations will range up to that of the highest station, Puskwaskau.

Based on the long term normal records, Valleyview station records mean annual temperatures 1.3°C warmer than Grande Prairie, while High Prairie has the same mean temperature as Grande Prairie. The Valleyview normal, being sporadic, was estimated by the Atmospheric Environment Service (1975), therefore the figure may not be too meaningful.

Temperatures during the four summer months from May 1 to August 31 are very similar for Valleyview, Grande Prairie and High Prairie while the

TABLE 3 COMPARISON OF CLIMATIC DATA FOR FIVE STATIONS
(based on 1941-1970 normals)

Station	elevation (m)	mean annual temp. (°C)	mean summer temp. (°C)	mean annual ppt. (mm)	% difference	mean summer ppt. (mm)	% diff.
Grande Prairie	669	1.2	13.6	442.0	±0	215.2	±0
High Prairie	594	1.2	13.5	450.6	+2	229.4	+7
Valleyview	762	2.5	13.5	-	-	-	-
Snuff Mountain L.O.	969	-	12.8	-	-	298.0	+28
Puskwaskau L.O.	972	-	12.6	-	-	273.3	+22
Spring Creek	-	1.4	-	538.0	+18	-	-

source: Atmospheric Environment Service, 1975

lookout towers record almost $1^{\circ}C$ cooler. Martz (1979) estimates that long term mean annual temperatures in the Spring Creek basin, just west of the Sturgeon Lake basin, would be $1.4^{\circ}C$ (compared to $1.2^{\circ}C$ for Grande Prairie). It seems probable that the Grande Prairie temperature records are reasonably close to being representative of average conditions over the Sturgeon Lake drainage basin.

There is probably less accuracy in applying the Grande Prairie precipitation data to the study area. Summer precipitation (May 1 to August 31) is lower at Grande Prairie than at any of three other stations (there are no precipitation records for Valleyview). The difference ranges from an extra 14.2 mm at High Prairie, to plus 82.8 mm at Snuff Mountain. It was estimated that mean annual precipitation in the Spring Creek basin would be about 538 mm (Martz, 1979), 18% more than the 442 mm recorded at Grande Prairie. This appears to be a reasonable correction to make for the Sturgeon Lake basin as well.

3.6 VEGETATION

The importance of vegetation to this study is in its capacity to intercept precipitation, slow overland flows, reduce raindrop impact erosion, contribute organic matter to the soil, stabilize soil structure and utilize stored soil moisture, thus influencing the amount of surface runoff and erosion which will occur in the watershed. Changes in the land use of an area invariably lead to changes in vegetal cover, thereby affecting its influence on erosion.

Sturgeon Lake lies in the mixed wood section of the Boreal Forest region near the Forest and Parkland region of Alberta (Rowe, 1972). The natural tree cover around the lake is largely trembling aspen and

balsam poplar with black spruce, white spruce, alpine larch, jack pine, lodgepole pine, water birch and white birch either mixed or locally dominant (North, 1976). Most of the watershed is forested.

The density of the forest stand and soil drainage conditions influence the shrub layer composition. Common shrub species include alder, willow, dogwood, buffalo berry, saskatoon, pin cherry, choke cherry, currant, wild gooseberry, prickly rose, wild rose, wild red raspberry, red elderberry, mountain ash, low bush cranberry, high bush cranberry, ground juniper, blueberry, dewberry, common bearberry and log cranberry (North, 1976; Greenlee, 1973).

Common forb layer species are twin flower, bunchberry, baneberry, Canada anemone, wintergreen, wild strawberry, vetch, fireweed, Indian paintbrush, western wood lily, wild lily-of-the-valley, Bishop's cap, Solomon's seal, western meadow rue, star flower, common nettle, northern bedstraw and clubmoss (North, 1976; Greenlee, 1973; Odynsky, et.al., 1956).

Grasses grow well in the aspen areas and the more open coniferous sites. Shrubs and forbs such as Labrador tea, feathermoss, plumemoss, horsetail, various lichens, tall larkspur and cow parsnip favor slightly damper sites. Moderately well-drained areas have combinations of white spruce, aspen and white birch while black spruce and larch predominate in the poorly drained depressions on organic and gleysolic soils (Greenlee, 1973; Boyacioglu, 1972; Odynsky, et.al., 1956; Moss, 1955).

Most of the forest areas have been burnt over at some time in the past. These fires may have been started by lightning or by man, either

intentionally or unintentionally. There are no records of the time or extent of the fires other than the memories of homesteaders and settlers. It is possible to reconstruct the history of past burns by mapping the age class patterns of the present vegetative cover. A photograph of the Young's Point area and another taken near Valleyview in the early 1950's shows relatively young forest regrowth indicating recent fires (Odynsky, et.al., 1956).

3.7 WATER BALANCE

Contributions of water to Sturgeon Lake are via surface runoff, groundwater seepage, several streams and direct precipitation in the form of rain or snow, while losses occur via evaporation and outflow through Sturgeon Creek. There are no streamflow records of Sturgeon Creek for a long enough time period to establish flow patterns and volumes. Evaporative losses from the lake may be measured or calculated in a number of different ways. For this study, Thornthwaite's procedures (1957) were used for establishing basin water balances for ten years. Utilizing data obtained in this manner, it was possible to calculate the evaporation from open water surfaces by using the equation:

$$E = P.E. + \tfrac{1}{2}D$$

where E is evaporation, P.E. is potential evapotranspiration and D is the deficit. All of the figures for evaporation at various shoreline soil moisture storage capacities are included in the tables in appendix 2.

Surface runoff contributions are from snowmelt and rainfall which fails to infiltrate the ground surface and so flows over the ground to the nearest downslope water body. Overland flow, along with interflow within the upper soil horizons, is of prime importance to this

study as it is by these mechanisms of transport that many sediments and nutrients are moved from land surfaces to the lake waters. A method of estimating the amount of water which is surplus and available for runoff is discussed in the following section, 3.7.1.

There are several small streams contributing water to the lake, all with relatively low flows, which tend to dry up in the late summer. These streams drain muskeg and marsh areas and usually have a considerable layer of colluvial and alluvial silts and clays on the banks and bottoms. There are about a dozen of these intermittent streams plus many smaller rivulet gullies which supply water to the lake from runoff during high flow periods (Gladish, 1976; Quaternary Geosciences Ltd., 1973).

Goose Creek is the main surface water source for Sturgeon Lake. It drains 352 sq km of land (Holecek, 1975, pg.2), and runs through three small marshy lakes. The waters of the creek are sluggish and highly colored but are an important spawning area for game fish. Bottom sampling shows a gradual decrease of productivity upstream (Schroeder & Walty, 1977; Schroeder, 1974; Bishop & Schroeder, 1972; Bishop, 1971b)

Groundwater inputs to the lake are also significant (Quaternary Geo-Sciences Ltd., 1973). Precipitation which percolates through the soil layers to the water table carries many nutrients in solution with it. These nutrients will eventually reach the lake or streams as groundwater flow through the zone of saturation (Ward, 1967). Sturgeon Lake is in a regional topographic low and, therefore, could be a significant groundwater discharge area (Quaternary Geosciences Ltd., 1973). A few small springs are found along the shores of the lake

and there may possibly be more below the water level. The conditions and characteristics of groundwater flow may have an important bearing on the effectiveness of different methods of sewage and waste disposal. Most of the information on groundwater aquifers as a source of water is for aquifers within the Wapiti Formation. This bedrock formation is considered to be the best source of groundwater, as one can be reasonably sure of obtaining a supply of relatively good water at shallow depths (Boyacioglu, 1972; Jones, 1966). These aquifers have long been the source of water for domestic use in the vicinity of the lake, including places such as Williamson Park..

3.7.1 THORNTHWAITE DRAINAGE BASIN WATER BALANCE CALCULATIONS

As there are no detailed streamflow records for the drainage basin, the water balance has been calculated by utilizing Thornthwaite's empirical procedures as published in 1957. This method of calculation is based on data for precipitation, potential evapotranspiration and soil moisture storage changes according the the following equation:

$$\text{Ppt.} = (\text{P.E.} - \text{D}) + \text{S} \pm \text{St.Ch.}$$

where Ppt. is the precipitation, P.E. is the potential evapotranspiration, D is the deficit, S is the surplus and St.Ch. is the storage change. According to this method, if Ppt. exceeds P.E. in any month, water will recharge the soil moisture supplies until the soil moisture storage capacity is reached and then any excess water is surplus and is available for runoff. Conversely, if P.E. exceeds Ppt. in any month, moisture is withdrawn from the soil until the soil moisture is fully utilized and then a deficit occurs.

Precipitation and temperature data were obtained for the Grande Prairie weather station and applied to the Sturgeon Lake basin (see section 3.5).

Potential evapotranspiration is influenced by temperature, wind velocity, barometric pressure, vapor pressure gradients, vegetation cover, the number of hours of sunlight and the orientation of slopes. Due to the complexity of the factors involved and the difficulty of obtaining accurate measurements for each factor, it is customary to calculate P.E. by using empirical procedures. In this case, it was obtained from Thornthwaite's P.E. tables (1957). The monthly P.E. patterns with maximum, minimum and mean values for the ten year period 1969-1978 are shown in figure 12. Figure 13 is a representation of the total annual P.E. for the same period. It can be seen from this that 1978 had higher than the ten year average P.E. Actual evapotranspiration (E.T.) represents the amount of moisture which is evaporated and transpired from the ground cover and is calculated by subtracting D from P.E.

Deficit and surplus values are obtained by calculating the water balance for different soil moisture storage capacities. These storage capacities vary with different combinations of soil texture and vegetative cover. MacIver (1966) conducted a study in the neighbouring Spring Creek watershed in which he estimated the storage capacities to effective root depth for various soil/vegetation combinations (see table 4). These capacities are mostly moisture held in retention storage (i.e. the difference between field capacity and wilting point) but it may also include some detention storage (i.e. the difference between pore saturation and field capacity), particularly in clay soils. Effective rooting depth will vary in part with soil texture. The estimations in the table take into account the generally low density of vegetative cover, the shallow rooting nature of the species present,

TABLE 4 SOIL MOISTURE STORAGE CAPACITIES TO EFFECTIVE ROOT DEPTH

soil texture	cereal grains	forage crops/pasture	forest
sand	25 mm	50 mm	150 mm
sandy loam	50 mm	100 mm	200 mm
loam & silt loam	100 mm	200 mm	300 mm
clay loam	100 mm	200 mm	300 mm
clay	100 mm	200 mm	250 mm

source: MacIver, 1966

TABLE 5 STURGEON LAKE DRAINAGE BASIN STORAGE CAPACITES

% of basin area	soil moisture storage capacity	vegetation/soil combination
1%	50 mm	cereal crops on sandy loam
4%	100 mm	cereal crops on loam & silt loam/ pasture on sandy loam
5%	150 mm	forest on sand
25%	200 mm	pasture on silt loam to clay/ forest on sandy loam
25%	250 mm	forest on clay
40%	300 mm	forest on loam, silt loam & clay loam/ muskeg

source: estimated by the author using soil and vegetation maps, air photos and field observations.

the lack of mature tree growth and the common presence of a poorly permeable clay subsoil. These values were applied to this study area and the percentage of the basin estimated to be in each category is shown in table 5.

The water balance was calculated on monthly data to obtain annual values for a ten year period, 1969-1978. The data obtained in these calculations are presented in tabular form for five different soil moisture storage capacities in appendix 2. The 25 mm and 300 mm storage capacity water balances have not been calculated here. The area within the drainage basin which would fall in the 25 mm category is so small that it was not taken into consideration. Although a very large percentage of the drainage basin is within the 300 mm soil moisture storage category, it was not calculated for the unadjusted precipitation water balance tables since the data for the 250 mm category are also applicable to the higher storage capacity. The calculations for the 250 mm storage capacity show zero surplus in all ten years so the 300 mm calculations would yield exactly the same data.

Figures 14, 15, 16 and 17 illustrate the water balance for the Sturgeon Lake drainage basin under various conditions. The first graph, figure 14, shows the 100 mm soil moisture storage capacity water balance for the 1969-1978 data. This long term average balance has a tendency to incorporate any extremes and show only the broad patterns. The pattern here is to have soil moisture recharge in the fall and during the beginning of the spring snowmelt, followed by a period of runoff of surplus water. The rise in P.E. in the spring utilizes all available Ppt. and the soil moisture until moisture deficit conditions occur in midsummer. Then only summer Ppt. is available to meet the needs of E.T.

WATER BALANCE PATTERNS

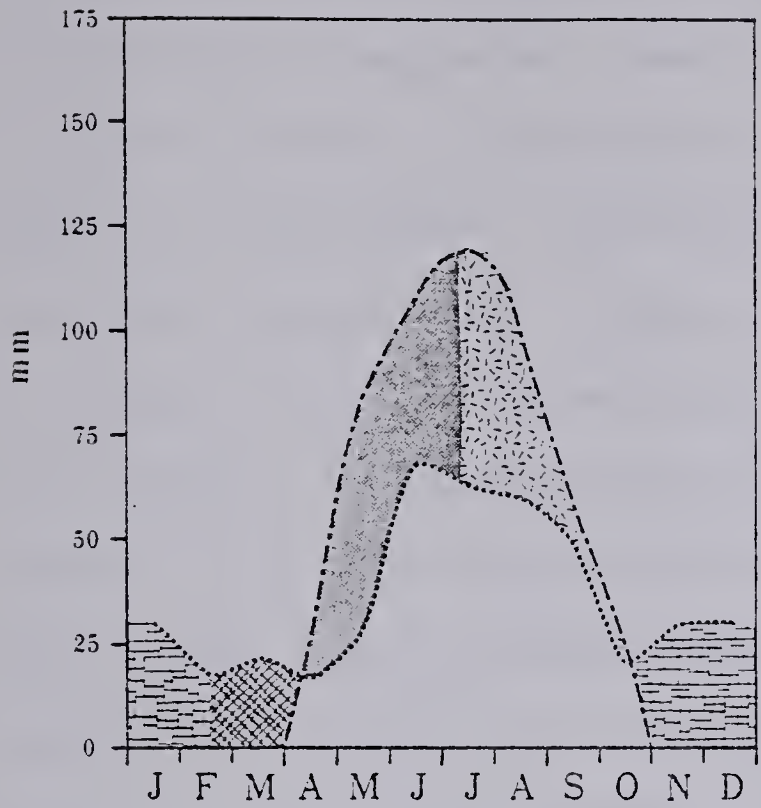


FIGURE 14 100 mm Storage 1969-1978

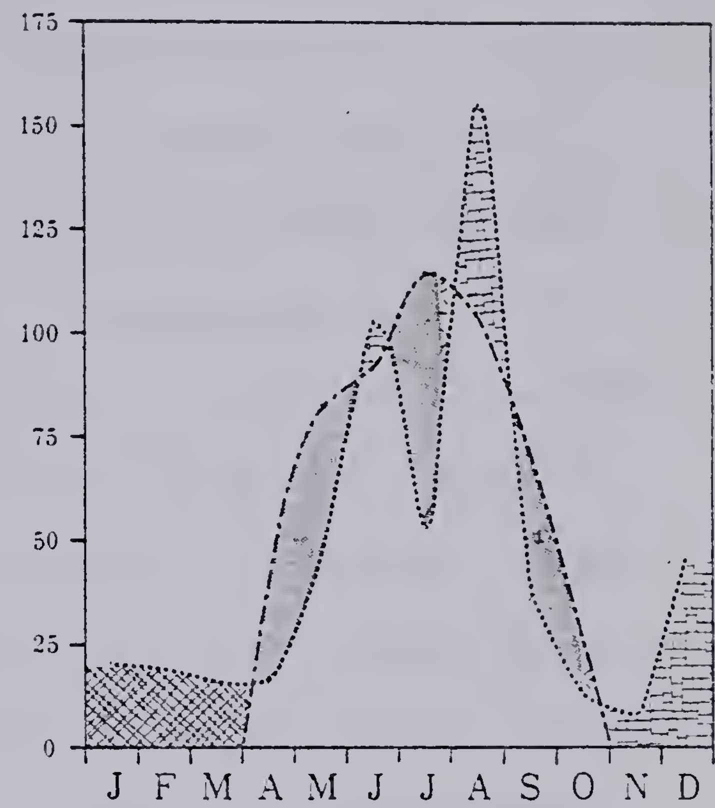


FIGURE 15 100 mm Storage 1976

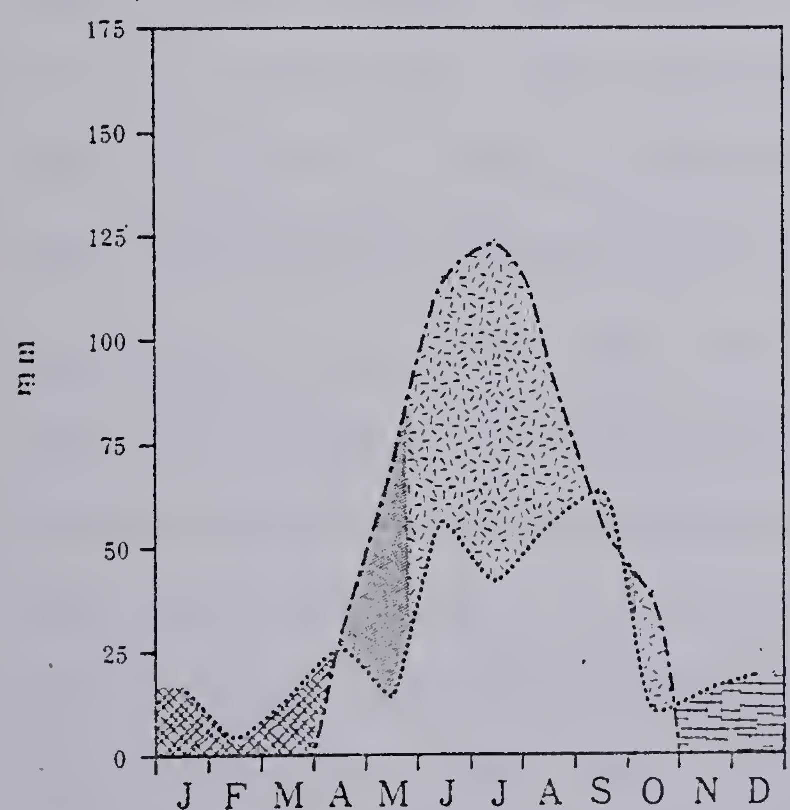


FIGURE 16 50 mm Storage 1978

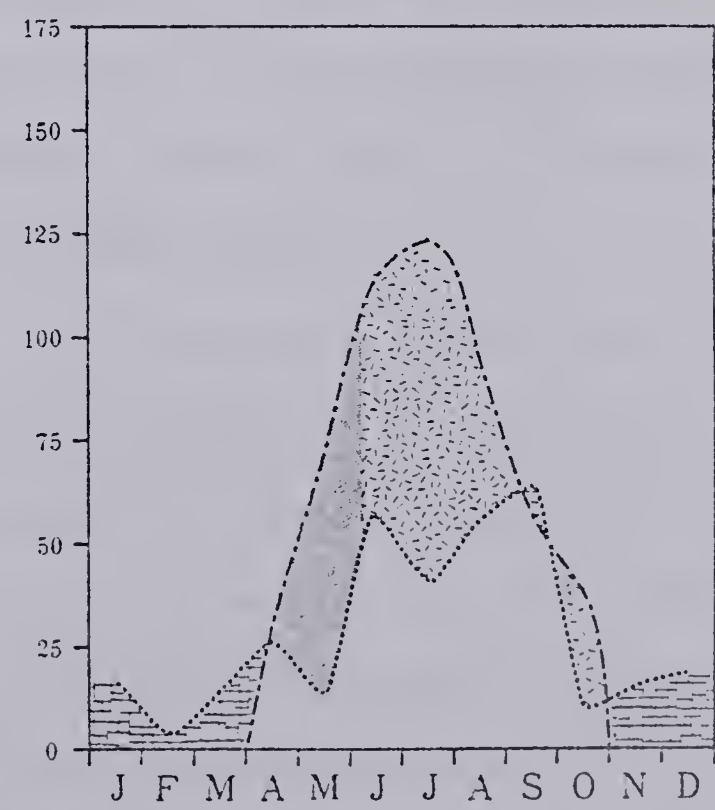


FIGURE 17 100 mm Storage 1978

soil moisture recharge

soil moisture utilization

potential evapotranspiration

water surplus

water deficit

precipitation

Source : Calculated by author according to Thornthwaite's procedures with data from the Atmospheric Environment Service

In actual fact, soil moisture is utilized at a decreasing rate as the wilting point is approached. However, the methods by which this factor may be included in the calculation in a significantly accurate manner are very complex. The straightforward procedures employed in this study are sufficient to obtain good comparative data. Figure 15 is a graph of the 1976 100 mm capacity water balance and is included as an example of a relatively wet year when deficits are minimal. Figures 16 and 17 show the 1978 water balance for 50 mm and 100 mm soil moisture storage capacity respectively. 1978, the year in which field work in the study area was conducted, was a relatively dry year. Figure 16, which represents only a small portion of the basin (see table 5), shows a surplus only in the spring, while figure 17, which represents conditions over most of the drainage basin, demonstrates that for this and for larger storage capacities there is no surplus at any time of the year. When the calculation is actually completed according to the data in table 5 and appendix 2, we find that in 1978 there was a total annual surplus of only ¼ mm (see table 6).

There can be little doubt that this figure for surplus water is low, even for a dry year. The major creeks and streams in the basin were flowing throughout the summer and responded to summer precipitation with higher discharges. It is not unusual for surplus runoff to occur during deficit or recharge periods if precipitation intensities exceed soil infiltration rates. There may also be concentrations of rain in parts of months that yield surpluses which are not recorded if monthly data are used. It is possible to calculate the water balance on a daily basis to overcome this problem but that has not been done for this study. These factors may account in part for the response of the

TABLE 6 COMPARISON OF CALCULATED SURPLUS FOR THE STURGEON LAKE BASIN AND SURPLUS FROM STREAMFLOW RECORDS FOR THE SPRING CREEK BASIN 1969-1978 (in mm)

Year	Surplus A[1]	Surplus B[2]	Surplus C[3]	Surplus D[4]
1969	1.42	3.18	7.55	51.20
1970	4.32	10.21	19.82	43.04
1971	2.84	5.44	13.15	85.24
1972	17.61	120.22	210.89	85.24
1973	3.19	37.03	76.70	74.27
1974	16.40	70.90	141.30	151.63
1975	14.35	26.75	13.78	27.29
1976	6.07	14.33	32.81	194.67
1977	0.47	39.00	134.77	178.92
1978	0.24	14.02	26.76	109.71
average	9.25	34.11	67.85	100.12

1. from original water balance calculation
2. from water balance calculated on +18% precipitation adjustment
3. from water balance calculated on +15% rain and +50% snow adjustment.
4. average basin runoff for Spring Creek drainage basin

source: calculated by the author using Thornthwaite's (1957) procedures; data from the Atmospheric Environment Service, 1978.

streams to precipitation occurance. However, the surplus figure still appeared to be low so it was cross-checked with streamflow records for other streams in the region.

Streamflow measurements for Sturgeon Creek made during June and July of 1978, while of little value on their own because of the short time span of measurement, were used to compare with the streamflow records for Spring Creek. These data are shown in appendix 3. While the values obtained are not exact, they are similar to one another, particularly when one takes into account the moderating effect of the control structure on Sturgeon Creek upstream of the point of measurement. Comparisons which were then drawn between the calculated water balance surpluses in the Sturgeon Lake basin and the streamflow records for the Spring Creek basin over each of the ten years from 1969 to 1978 indicated that the calculated surplus figures are indeed too low (see table 6).

Corrections were then made to the data used in the original water balance calculations. There were two ways in which this was done. The first was to add 18% onto the total precipitation for each month over the ten year period. As was indicated in section 3.5, this appears to be a reasonable correction factor for the difference between precipitation values for the Sturgeon Lake area and those for Grande Prairie. The second method was also to adjust the precipitation values but, in this case, it was to correct the measured amounts for discrepancies due to undercatch. The correction is made by adding 15% to each month's rainfall and 50% to each month's snowfall. The method has been employed in a number of Russian IHD projects and has since been utilized in several Canadian studies (Laycock, 1978; Laycock, 1973; Wight, 1973; Kakela, 1969). Tabulated results of the calculations for both of these

corrections are presented in appendix 2. It is also possible to make corrections to adjust evapotranspiration values from muskeg areas. E.T. losses are generally thought to be well below those calculated by using Thornthwaite's tables due to the insulating effect of the organic mat which keeps the water below the mat quite cold (Park, 1979; Laycock, 1978; Laycock, 1973; Wight, 1973; Laycock, 1967). There are no generally accepted correction factors for this effect so no adjustments were made in this study, although it is worthwhile to recognize that the condition exists and may influence the water balance. All of these corrections are generally utilized only for comparative purposes.

While these corrections did increase the surpluses for the Sturgeon Lake basin to levels which compared more favorably with the Spring Creek streamflow records for most years and tended to follow the same patterns of increased and decreased flow (see table 6), there are still some major discrepancies in the magnitude of the changes. This is probably due partly to errors incurred for the reasons mentioned previously (i.e. precipitation intensities and timing) and partly to the difficulties which are encountered when data are transferred from one area to another. The water balance calculations for the Sturgeon Lake area were based on data recorded 80 km away and compared to streamflow records measured in an adjoining basin to the southwest. The variations which are estimated to occur in the climatic data have already been discussed in section 3.5. Variations should also be expected for the transferred streamflow records, even though similarities in the data have been indicated above. Comparisons were made between the Spring Creek records used and the total streamflow records for each year from 1969-1978 for the Beaverlodge and West Prairie

Rivers to indicate how streamflows vary over space. The Beaverlodge River, being much closer to Grande Prairie than Spring Creek, is more likely to respond to the precipitation records with less deviation and the same is true of the West Prairie River and the High Prairie climatic data (see appendix 3). While the patterns for increased and decreased surplus are similar for all three basins, they are not the same and where one basin has increased runoff in a given year, another may have decreased runoff (e.g. 1972 for Beaverlodge and West Prairie). So, when one is using data for one area to fill data gaps in another area, this must be considered in the final analysis.

Since the climatic data used to calculate the water balance for the Sturgeon Lake watershed were taken from a station 80 km away and there is a good indication that these data are not, in fact, accurate for the study area, even a correction for total precipitation will not account for differences in the timing and duration of storms. For this reason, there are some major deviations between the calculated runoff and the estimated streamflow. There are many other regional refinements of the Thornthwaite procedure which may be used in the calculations but, since there are so many data deficiencies for this study area, further refinement would involve too much estimation to be of much value. Despite the problems encountered even to this stage, using the Thornthwaite procedure aids in developing a better understanding of the water balance. By considering all of the variables involved and the probable causes of the errors, it seems reasonable to estimate that the runoff in the Sturgeon Lake drainage basin averaged approximately 68 mm for the 1969-1978 period and was in the order of 27 mm in 1978. These estimations are probably still too low but will suffice

for this study.

3.8 WILDLIFE, BIRDS AND WATERFOWL

There are abundant wildlife near the shores of Sturgeon Lake as evidenced by tracks, browse, scats and sightings. Such animals as bear, moose, elk, lynx and coyote live in the area (Gladish, 1976).

A study conducted to list the birds in the area near Sturgeon Lake, the relative abundance and habitats of each species, identified 81 species. Although there is a substantial variety of species and large numbers of birds are in the area, Sturgeon Lake does not represent an area of any unique species or habitat. No attempt was made to determine whether or not increased activity by man around the lake would affect bird populations (Tretiak, 1976).

An appraisal of waterfowl utilization of Sturgeon Lake has shown that the greatest use is made of the lake by diving ducks during the autumn staging period. The lake is a marginal habitat for nesting and production although it would probably be more important during drought periods. The western arm of the lake and twenty miles of Sturgeon Creek with its oxbows are the most productive areas near the lake. The indications are that the lake would be managed best as a staging area. The many marshes and small lakes within the basin, although not major production areas, are better suited for waterfowl production than Sturgeon Lake is, especially in view of the lack of competition for other uses (Gladish, 1976; Lacy, 1969).

3.9 FISH

The fish of Sturgeon Lake are an important resource, with both sport and commercial fishing being very popular. Many birds in the area as well as some fish species use forage fish as a food source (Bishop,

1977). Whitefish are the most numerous fish in the lake. Walleye and northern pike are popular game fish. Trout perch, yellow perch and spot-tail shiner are fairly common and, although they are not often fished for, they are important as forage fish. White sucker may be of commercial potential in the future. Longnose sucker, ling, burbot and arctic grayling are also found occasionally in the lake (Bishop, 1977a; McDonald, 1973).

Goose Creek is an important spawning area for walleye and pike, with pike migrating as far upstream as Goose Lake. Walleye prefer the gravel and rubble bottom in the first kilometer of the creek close to the lake (Schroeder & Walty, 1977). There is some evidence of a small spawning migration to Pelican Lake for both pike and walleye but none of the other small creeks have any apparent spawning value. These fish probably also spawn in the lake (Bishop & Schroeder, 1972). Questionnaire returns from fishermen indicate a decrease in the numbers and size of walleye over the years. Pike have apparently also decreased in size but the numbers have remained constant (Gladish, et.al., 1975).

The Sturgeon Lake commercial whitefish fishery is one of the most productive in the Peace Region. The lake has supported a commercial fishery since 1943 with 12 to 16 commercial fishermen utilizing it until 1968 when new license zoning increased the numbers of fishermen dramatically to about 70 per year. 18,200 kg. of whitefish per year are taken in about three days on commercial licenses, plus an additional 13,600 to 18,200 kg. per year taken during the year round domestic Indian net fishing (Bishop, 1971a). Good commercial fishing records show that whitefish populations have decreased in size, growth rate,

condition factors and numbers over the years, indicating that Sturgeon Lake simply cannot produce jumbo sized whitefish at the rate of 31,800 kg. per year on a sustained basis. The decrease in numbers taken per net has been attributed to the smaller size of the fish and to the fact that many commercial license holders are inexperienced anglers who are out to fill their freezers rather than catch fish to sell. It was found that many whitefish were dying of natural causes before they grew large enough to be taken in the 16 cm nets used by commercial fishermen, indicating that competition was too great to allow higher growth rates. Fisheries biologists recommended that the mesh size be reduced to not less than 14 cm from not less than 16 cm to reduce the numbers of whitefish and, therefore, the excessive competition (Bishop, 1977b; Bishop, 1973; Bishop, 1971a).

Summer fish kills are not uncommon at Sturgeon Lake and seem to coincide with the *Anabaena* bloom, a blue-green algae. It has been postulated that suffocation along with temperature and chemical stress in a few localized areas cause the fish kills. The algae bloom forms a dense scum on the surface of the water, inhibiting light penetration. Low dissolved oxygen and high carbon dioxide levels causes distress and dying of fish. The decomposition of *Anabaena* releases a toxic substance that may also contribute to fish kills. According to Frank Bishop, the local fisheries biologist, there is not much that can be done to prevent the fish kills as they now occur, due to the large area involved and the intricacy of the systems involved so he recommends that nature be allowed to take its course (Bishop, 1977b; Bishop, 1973; Bishop, 1971a).

3.10 PRESENT USES

Sturgeon Lake is considered by the Peace River Regional Planning Commission to be the best lake in the region for a wide range of uses. The prime emphasis is upon varied recreational uses and as a source of water but the drainage basin also supports a forest reserve, oil and gas development, an Indian reservation, agriculture and grazing. Figure 18 depicts the areas of the basin which are utilized in the various ways.

3.10.1 AGRICULTURE AND GRAZING

The beginning of agriculture around the lake by white man was by homesteaders at about the turn of the century. These settlers, arriving via the Edson-Grouard Trail, settled mainly on the western arm and the south shore of the lake. Today, there are seven farms on the lake shore, all on the western arm. It is mostly mixed farming which is undertaken in this area with the emphasis on hay, rapeseed and beef cattle, although some sheep, swine and poultry and also kept (Jones, 1966). Approximately 10% of the total drainage basin has been cleared for agricultural use (P.R.R.P.C., 1978).

There are no grazing areas to the north of the lake except where it occurs on private land. The Valleyview grazing reserve, some 50 sections of which lie in the forestry reserve yellow zone within the drainage basin, east of Long Lake (see figure 19), is presently being cleared for improved grazing. Livestock are also maintained on farms around the western arm of the lake and south of the lake.

3.10.2 INDIAN RESERVATION

The Sturgeon Lake Indian Reserve #154 on the south shore of the lake and #154A on the northeast shore were held for the Cree Indians

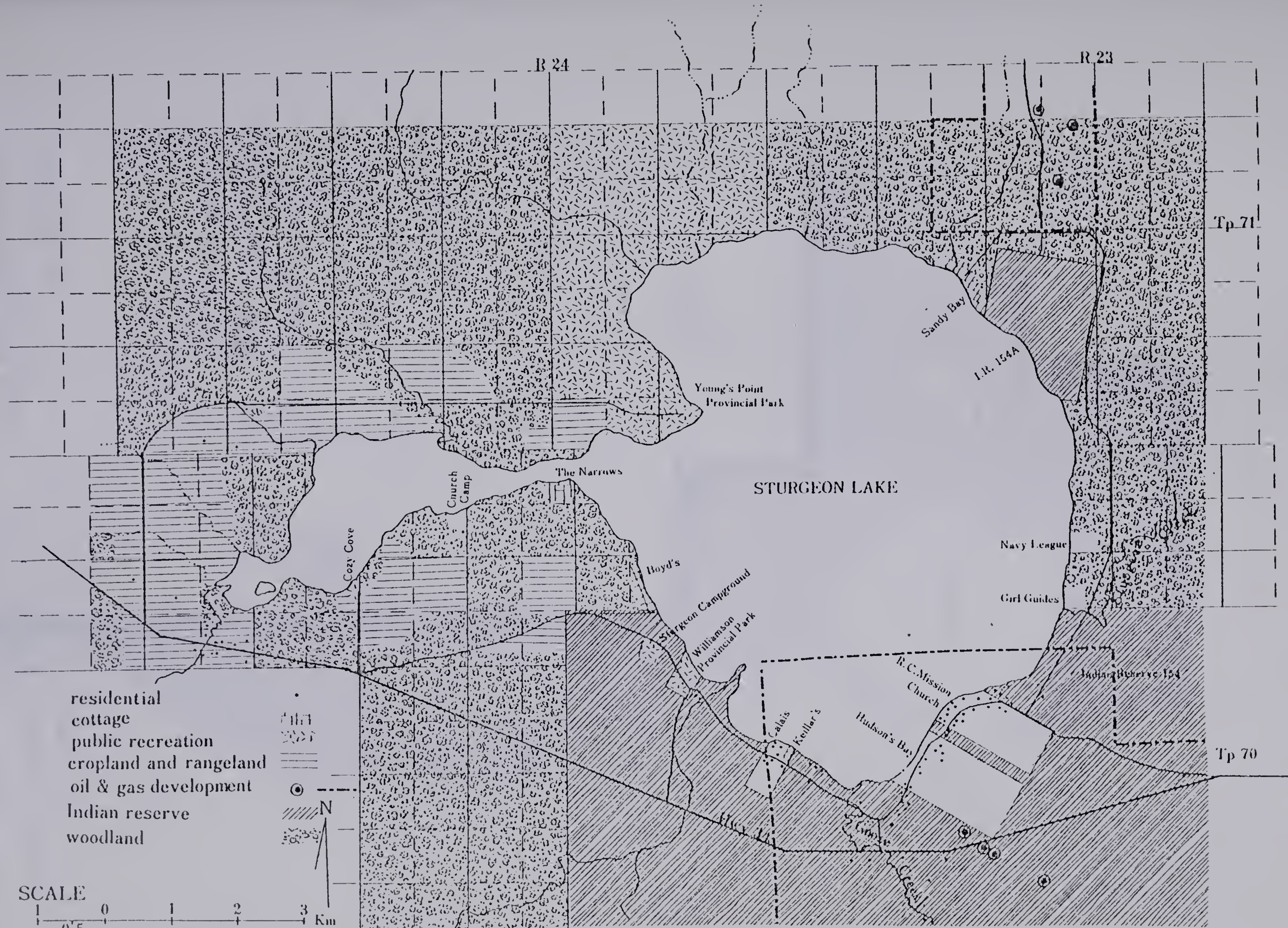


FIGURE 18 PRESENT LAND USE NEAR LAKE

Source: Peace River Regional Planning Commission Records ; Author

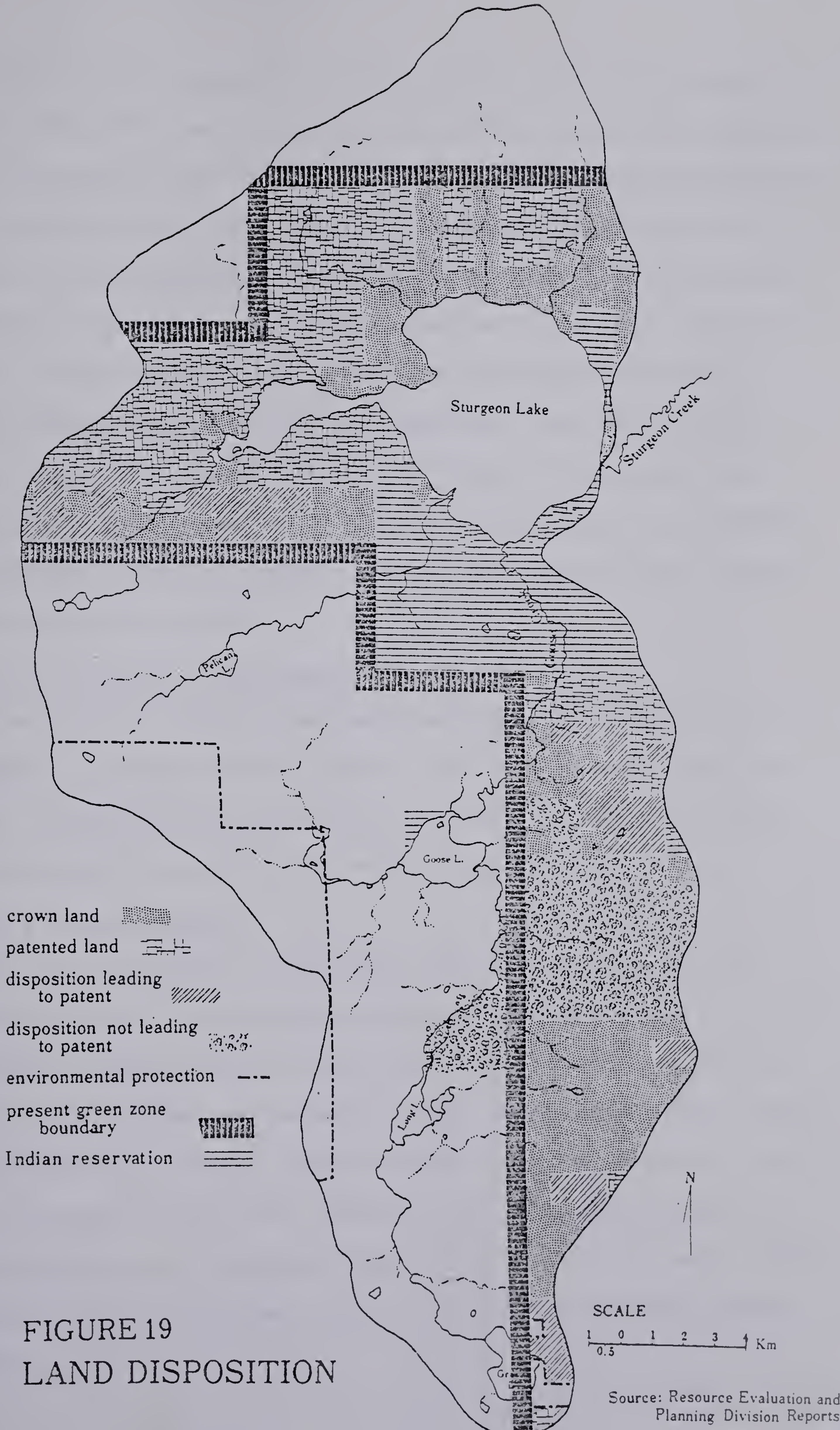


FIGURE 19
LAND DISPOSITION

Source: Resource Evaluation and Planning Division Reports

according to the agreements made in Treaty #8. The reserve lands comprise some 25% of the lake shore. The 1976 census records a population of 600 Indians on the reserve with most of the population concentrated in a sprawling lake shore community centered on the Mission Church. There is no development on reserve #154A thus far. The Indians rely heavily on the hunting and fishing resources of the area (Wight & Mack, 1975). Most households have a vegetable garden and some stock are kept with minor subsidiary haying operations. They have recently begun to look at alternate means of livelihood to supplement this. The main project undertaken so far is the development of a campground and marina to cater to tourists coming to the lake (for more information see section 3.10.6).

3.10.3 OIL AND GAS DEVELOPMENT

The whole area around Sturgeon Lake has been explored for oil and gas deposits and seismic work was done on the lake bed in the winter of 1973. Amerada Hess now operates several wells to the north of the lake and south of reserve #154 (McDonald, 1973).

3.10.4 FOREST RESERVE

Almost all of the land in the drainage basin is still crown land, including 35% of the shoreline of Sturgeon Lake (see figure 19). Most of this is designated as forestry green and yellow zones. North of the lake, the green zone is under a forest management agreement which grants the North Canadian Forest Industries Ltd. ownership and control of the timber for that area. However, the timber there is not yet considered to be of commercial value and so there are no active forestry operations (pers. comm. with O. Boyster, regional forest ranger, 1978).

To the south of the lake, a portion of the yellow zone is currently being cleared for grazing use. The green zone areas to the south are in the transitional 'O' phase while the area is under study for a regional Sturgeon-Puskwaskau management plan being conducted by a group of interested agencies under the coordination of the Resource Planning Branch of Alberta Energy and Natural Resources. A preliminary land use plan by that group for 2½ townships in the Spring Creek area designed to determine the suitability of the land for agriculture and settlement was completed in 1979. Approximately 18 sections (½ township) of the Sturgeon Lake watershed was included in their study plot. In their interim report, virtually all of the Spring Creek study area which falls inside the Sturgeon Lake watershed was recommended for watershed protection, watercourse protection or conservation (Resource Planning Branch, 1979). These recommendations will be examined more closely in chapter 6.

3.10.5 VILLAGES AND TOWNS

The settlement of Sturgeon Heights is located south of the western arm of the lake (see figure 18). Until recently, a gas station and store served the village but these have closed down and it is now simply a collection of houses. The population of 17 (1976 census figures) is largely Metis. Water supplies are from groundwater aquifers and most of the homes still have only basic indoor plumbing (i.e. kitchen sink pipes but not toilets).

The village of Calais is situated on a small block of land within the boundaries of Indian Reserve #154 (see figure 18). It was settled near the Mission Church and the Hudson's Bay post before the reserve was created. A post office and small store are still in operation but

the tourist cabins have been closed. The census includes the population of Calais with the figures for the reserve but there are only three white or mixed families living here along with a few Indian families.

Thirteen kilometers east of the lake, the town of Valleyview is steadily growing. The population rose from 1077 in 1961 to 1716 in 1976. The town is situated at the junction of highways 34 and 43 and serves many travellers going farther north. Although Valleyview is not actually in the drainage area, it has depended on a steady flow of water in Sturgeon Creek since 1957 when it installed a sewage and water system. A water level control dam had been installed at the outlet of Sturgeon Lake in 1949 by Ducks Unlimited to enhance the waterfowl habitat around the lake. Due to some problems with the small spillway and the fixed crest, the structure was altered and adjusted on various occasions to accommodate certain high or low lake level conditions. Then in the winter of 1959-60, the town's water supply was jeopardized by low water levels which caused poor water quality and ultimately allowed the creek to freeze solid, cutting off all water. The end result was that a new dam was constructed on the lake outlet in the SE¼, Sec. 29, Twp. 70, Rng. 23., W. 5 by Alberta Environment in 1969 (communications between Valleyview Town Council and the Department of Water Resources, 1958-1969). The new dam is 37.2 m wide, 6.4 m deep, 4.0 m high at the face, 2.4 m high at the tail, and has a fixed crest at 677 m A S L. This structure is twice as wide as the original Ducks Unlimited dam and the crest is 15.24 cm lower. A 91.4 x 91.4 cm control gate provides a continuous water supply for the town if the lake drops below the crest height.

There is also a fish ladder mechanism of individual concrete cells with fixed crests at 0.3 m vertical intervals from 676 m to 677 m A S L. The fish ladder was poorly designed originally and was inoperative whenever the lake level fell below crest height. Subsequent modifications to the dam have reduced the problems with the fish ladder (Anderson, 1975).

The stabilization of the lake level which resulted from the construction of the control structure has caused some problems along the shorelines. Flooding of the natural shorelines during spring runoff, reduced beach development and, as has been mentioned in section 3.1, higher summer lake levels have all resulted. This matter will be discussed further in chapter 5.

3.10.6 RECREATION

The recreational uses of the lake are the most prominent uses at present and are of the greatest concern to the responsible planning authority, the Peace River Regional Planning Commission (P.R.R.P.C.). The lake is popular for regional family type camping, fishing, swimming and boating (Gladish, 1976). Estimates of numbers of boat users on the lake, based on creel census, boaters interviews, boat counts and observation established relative recreational boating uses to be 70% fishing, 16% pleasure boating and 14% water skiing (Bishop, 1977a). Noon to 4:00 P.M. is generally the busiest time of day and July is the busiest month. There are currently twelve developments on the lake shores that are geared to recreational uses. Of these, three are private cottage areas, four are commercial resorts, one is a church camp, two are leases to the Boy Scouts and the Girl Guides

and two are provincial parks.

There are presently 110 privately owned cottage units and 44 undeveloped lots near the lake. The six cottages at The Narrows (formerly Millers Subdivision) on the south shore of the west arm of the lake were bought up with a large parcel of land for a proposed development site. The development stopped after 43 lots were made available, four of which have been bought but not developed. Boyd's Co-op is a private cooperative which is a linear string of 56 cottage lots, each with a private piece of shore, on the southwest shore of the lake. The 49 Sandy Bay cottage lots are located on government leased land on the northeast shore of the lake. Water supplies for the cottages are wells tapping groundwater aquifers. Sewage facilities are outhouses, from which some of the wastes would be filtered through the earth, into the groundwater and then into the lake. There are at least two cottages which have drain pipes from sinks running directly into the lake (pers. comm. with Archie Stirling of Boyd's Co-op, 1978).

Of the four commercial resorts near the lake, only one supplies cabins and one is no longer in business. The cabins at Calais were closed as of 1978. Keillers resort is now run on a four month rental basis and the cabins, which are very small, are usually rented out to the same people every year. Boat rentals are no longer available at Keiller's and the dock is for the use of cabin renters only. Cozy Cove, on the southwest shore of the west arm, is the most active commercial resort. There is a campground, a small concession stand and a boat rental business located here. The boat rentals draw a large number of tourists to Cozy Cove. The original plan for the

Sturgeon Lake campground run by the Indian Band was for a large sophisticated campground and resort with cabins, horse stables, an airstrip, a marina, a store and many other facilities. The plan was modified to a design which is to develop in stages over a period of years. The first stage opened in 1978 with 110 camping units, a playground, water and sewage facilities. A small laundromat, a groceteria, beach and boating facilities are to be developed next. The Indian Band was very concerned that conflict for business with Young's Point Park would render their larger plan impractical but, as their location is more amenable to stopover traffic from the highway than the park is, the province feels that there will be no problems.

The Baptiste Church Camp on the south shore of the west arm consists of two large buildings and several small cabins near a small but good beach. The beach is used mainly for swimming although some boating is also in evidence. The leases for the scout and guide camps are just north of Sturgeon Creek on the east shore of the lake. There are no buildings there as the camps are designed to provide a tenting experience.

Williamson Provincial Park is an 18 ha park located on the southwest shore of the lake within the Indian Reserve Boundaries. It has a swimming area, a good beach, a concession stand, a boat dock, a day use area with 35 sites and a 62 unit camping area. The camping units are going to be phased out as the Indian run campground expands. The boat launch and dock are used a great deal by fishermen and pleasure boaters and the park itself is also heavily used. Young's Point Park opened in 1978. It was designed to be a low density use park covering

PHOTO 3: WILLIAMSON PROVINCIAL PARK BEACH (SAMPLE SITE F).

This photograph was taken in late May when most of the recreational use of the area was for fishing. The boat launch is on the left hand side. The center section of the beach was later roped off for swimming use.

1093 ha Four-fifths of the park has been zoned for interpretive and hiking trails with the remaining one-fifth being used for camping areas, water and sewage facilities, a playground, access roads, beaches and boating facilities. When completed, it will contain 150 overnight units for trailers, 100 camping sites and 125 day use sites (Greenlee, 1973; Turner, 1973).

Concern over the development on the lake shores was brought to the forefront with the proposal by a real estate firm to develop 678 ha on Sec. 28, 29, 32 and 33, Twp. 70, Rng. 25, W. 5 into a small townsite. The proposal was for: 302 ha of recreational land with a lake shore park on 3.2 km of beach, ski and tobaggan hills, a riding stable, a golf course and a green belt; 365 ha of residential land with some 1500 lots; and 12 ha for a school and commercial uses. The land is presently being used for low yield grain farming on class 2 and 3 CLI agricultural land, 6 cottages at the Narrows, the church camp and a nuisance grounds. The major portion of the land is still natural environment of open areas with marsh grass, aspen treed areas and muskeg areas with spruce trees. The Peace River Regional Planning Commission became concerned over the subdivision of agricultural land (subdivision of CLI classes 1 to 4 land is not permitted) and felt that the new town would be too close to existing settlements. Also, 75% of the proposed beach area is an important waterfowl area, the development of which would change 20% of the best waterfowl areas on the lake (Peace River Regional Planning Commission, 1974).

In 1977, the western arm of the lake was designated along with fourteen other Alberta lakes as a 'restricted development lake'. The

various regional planning commissions, in this case the P.R.R.P.C., were asked by the provincial government to submit development plans for each of the regulated lakes which lie within their planning areas. The Sturgeon Lake Management Plan was submitted in June, 1978 but, until it has been accepted and new zoning laws put into effect, any development applications are being held (pers. comm. with the P.R.R.P.C., 1978).

Examination of the potential problems on the lake highlighted use conflicts between: shoreland and weedbed clearing versus fish and waterfowl; private versus public recreational use; boat use versus waterfowl; and fishing versus waterskiing.

Several studies have been conducted for data collection to aid in establishing a wise development plan for using the lake's resources. The next step in this study is to examine the processes at work within the lake itself in order to gain a better understanding of how the activities on the land around the lake and on the lake waters may affect these processes, thereby causing changes in the lake ecosystem cycles.

CHAPTER 4

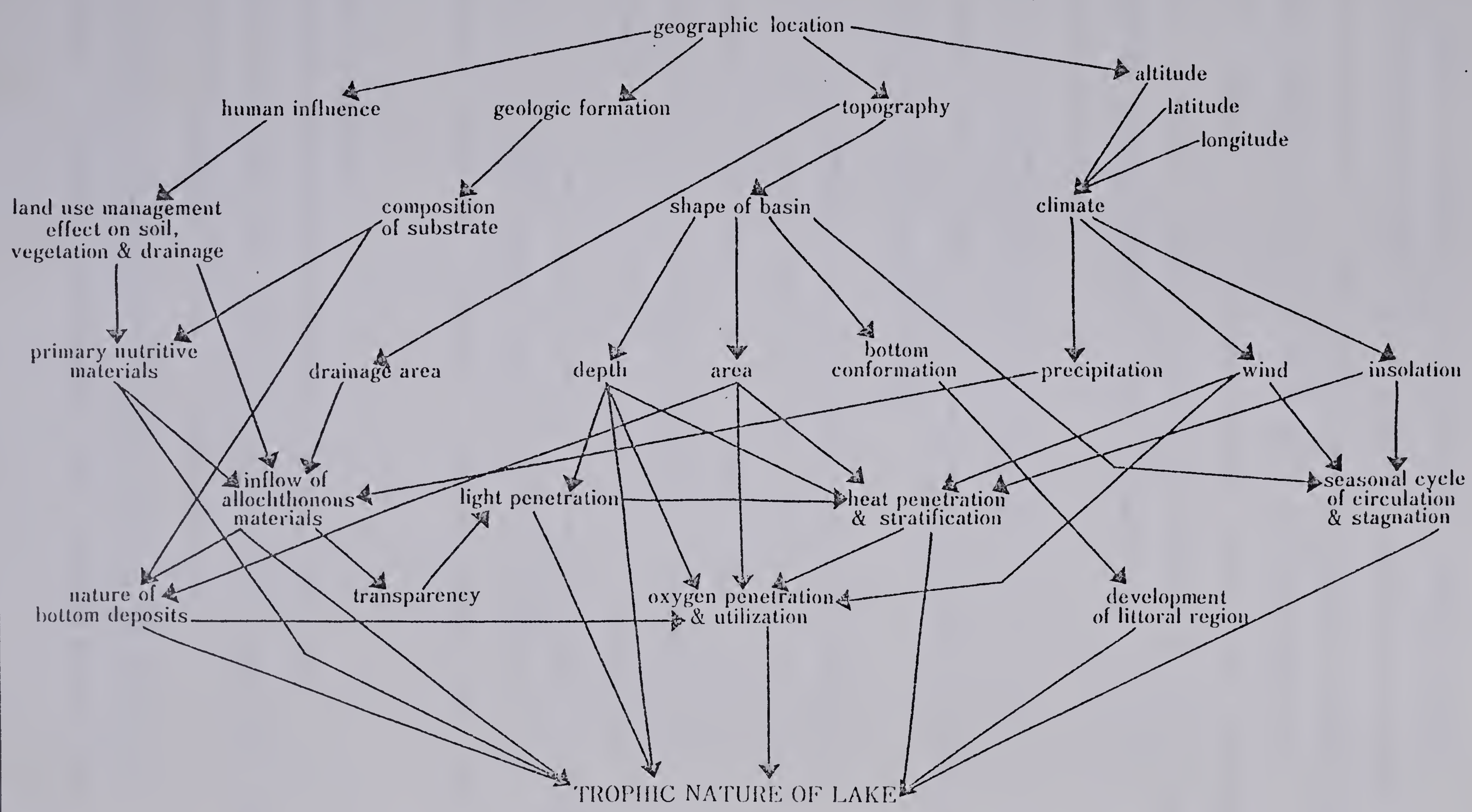
LIMNOLOGICAL PROCESSES, WATER QUALITY & SOURCES OF POLLUTANTS BACKGROUND INFORMATION

"It has long been recognized that all components of the drainage basin are influential in regulation of lake metabolism" (Wetzel, 1975, pg. 418). It follows, therefore, that changes in lake metabolism should be largely attributable to land based activities and that the lake waters can be studied to supply input to land use management. The chemical, physical and biological components of Sturgeon Lake can provide valuable input in planning for the future use of the lake and its watershed. This kind of management planning policy would acknowledge and take into account the interactions which make up the total lake system.

Great progress has been made in recent years in the study of chemical and physical properties of water and the dependence of the life processes on these (Mortimer, 1974; Schindler & Lean, 1974). In this chapter, I attempt to draw together some of the concepts of lake dynamics which are fundamental to the chemical and biological aspects of lakes in general. It is my intention to simplify the extremely complex cycles involved while still offering a reasonably accurate description of the processes. Only those processes which apply specifically to temperate zone lakes similar to Sturgeon Lake are examined. These processes and concepts will be applied to the analysis of data gathered for the Sturgeon Lake case in Chapter 5.

A lake system is characterized not only by the parts which form the whole, but also by interaction among the parts. The flow diagram in figure 20 represents some of the main pathways of interaction among

FIGURE 20 PRODUCTIVITY FLOW DIAGRAM



Source: Rawson, 1939

the major physical factors in a lake system which together produce organic matter from inorganic materials through the process of primary production by plant life. These pathways are not mutually exclusive and the various factors do not act on their own. It is difficult to separate the effect of one factor from another and, while one can assume that some factors have a greater influence than others, all of the potential influences causing changes to a lake system should be examined when studying the system.

The part of the diagram with which I am primarily interested is the human influence arm with its supply of nutrients for primary production and the effects of this on water quality.

Water quality is a description of those traits which are distinctive to a body of water in association with the intended use of the water. It is influenced by both natural and man induced factors, depending on the history of the lake and the opportunities available for the drainage system to take substances into solution or to carry them in suspension. Water is never pure in nature. It contains gases, nutrients and chemical salts which together with the physical condition of the water determines the nature of aquatic life (American Water Works Assoc., 1950).

4.1 PHYSICAL PROPERTIES

The measurement of the physical properties of lake waters defines the environment in which the plants and animals live and can also affect the way in which the biochemical cycles and reactions occur.

As has been stated in the definition of water quality, the objectives must be outlined in terms of some specific use. The main uses of the

waters of Sturgeon Lake are recreational and as a water supply for the town of Valleyview, along with an interest in protecting the aquatic life in the lake. Canadian guidelines and suggested limits for each of the parameters tested for in this study in terms of these uses are listed in table 7.

4.1.1 ENERGY INPUT

The solar radiation regime is of fundamental importance to the dynamics of freshwater ecosystems. Light directly controls the growth of plants which can not utilize nutrients without this energy source. The amount of light which is available for use by aquatic organisms varies with depth, transparency, angle of incidence, hours of daylight and biotic light attenuation (Hickman, 1979b; Mortimer, 1974; Schindler & Lean, 1974; Brown, 1971).

The bulk of the sunlight which penetrates into a water body heats the lake without causing major chemical changes in the absorbing body (Ernst, 1977). The dissipation of this heat affects thermal structure, water mass stratification and circulation patterns which in turn affect nutrient cycling, distribution of dissolved gases and biota and the adaptations of organisms (Wetzel, 1975).

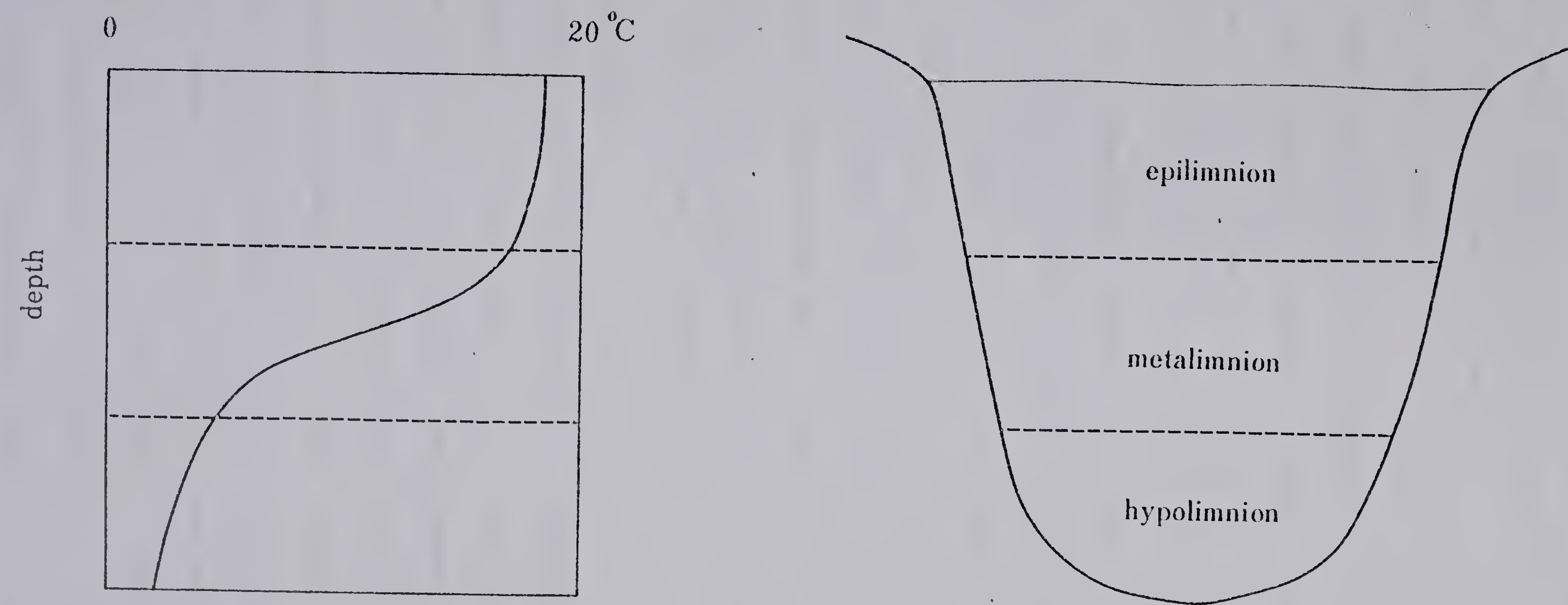
The thermal conditions in a lake may create a temperature gradient consisting of three regions. An idealized representation of this temperature profile is shown in figure 21. The upper layer, or epilimnion, absorbs 99% of the total incoming radiation. It is characterized by a small decrease in temperature with respect to depth. A zone of sudden temperature decrease underlying this is called the metalimnion or thermocline. The special importance of the thermocline is that it

TABLE 7 CANADIAN WATER QUALITY GUIDELINES FOR SPECIFIC USES

PARAMETER	DOMESTIC CONSUMPTION MAXIMUM	DOMESTIC CONSUMPTION OBJECTIVE	RECREATIONAL	AQUATIC LIFE PROTECTION	WILDLIFE AND STOCK WATERING
alkalinity as $CaCO_3$	30-500 mg l^{-1}			20 mg l^{-1}	
ammonia (NH_3)	0.5 mg l^{-1}	0.01 mg l^{-1}		0.02 mg l^{-1}	
chloride (Cl)	250 mg l^{-1}	250 mg l^{-1}			
color	15 TCU	15 TCU	100 TCU		
dissolved oxygen				4.0 mg l^{-1}	
hardness as $CaCO_3$	120 mg l^{-1}	120 mg l^{-1}			
iron (Fe)	0.3 mg l^{-1}	0.05 mg l^{-1}		0.3 mg l^{-1}	
nitrate & nitrite as N	10 mg l^{-1}	0.001 mg l^{-1}			20 mg l^{-1}
nitrite (NO_2)	1.0 mg l^{-1}	0.001 mg l^{-1}			10 mg l^{-1}
pH	6.5-8.5		6.0-9.0	6.5-9.0	
ortho phosphate as PO_4	0.065 mg l^{-1}	0.065 mg l^{-1}			
total phosphate (PO_4)	0.1 mg l^{-1}			0.025 mg l^{-1}	
Secchi disc			1.2 m		
sodium (Na)	270 mg l^{-1}				
sulfate (SO_4)	500 mg l^{-1}	150 mg l^{-1}			1000 mg l^{-1}
suspended solids				25 mg l^{-1}	
temperature	15 C	15 C	30 C		
total dissolved solids (TDS)	500 mg l^{-1}				2500 mg l^{-1}
turbidity	5 JTU	5 JTU	50 JTU		

source: McNeely, et.al, 1979 and Addendum to McNeely et. al.

FIGURE 21 IDEALIZED SUMMER THERMAL STRATIFICATION



Source: Wetzel, 1975

forms a barrier between the upper and lower regions of the lake, indicating the depth to which effective mixing is occurring. The hypolimnion is nearest to the bottom of the lake and is a zone where water is denser than anywhere else in the lake. Water reaches its maximum density at 4°C and, in lakes which develop this temperature profile, spring and fall turnover occurs when surface water is warmed or cooled to a degree which makes it denser than the waters below. The lake then goes through a period when its waters are well mixed until a new temperature gradient forms. The temperature profile may disappear when the sedimentation process causes the lake to become so shallow that wind driven currents maintain circulation of water to all depths (Ruttner, 1975; Wetzel, 1975). There is no evidence to indicate that Sturgeon Lake develops a thermocline during the summer, probably due to wind induced mixing and the shallowness of the lake. However, it is probable that it will be inversely stratified beneath the ice in the winter (Hickman, 1979a; Hickman, 1979b; Hickman & Jenkerson, 1978).

4.1.2 LAKE CIRCULATION

Knowledge of movement within the lake waters is important to any pollution study. Dispersion of pollution agents in a lake is dependent on lake circulation which in turn is highly wind dependent. Convection currents caused by differential heating of the lake waters may also cause some water movement (Rogers, et.al., 1975; Brown, 1971). A shallow lake that is often windswept, such as Sturgeon Lake, may not show evidence of thermal stratification due to good vertical mixing. A 1/3 meter wave can mix up to a 10 meter depth of water (Fish, 1972). Hickman (1979a), using Sverdrup's wave period formula, found that wind velocities of 20-25 km h^{-1} were sufficient to mix the waters of Cooking

Lake, Alberta to a depth of 5 m. Circulation due to currents set up by wind and wave action resuspends bottom sediments, releasing some nutrients and is important in water aeration and distribution of organisms, elements and food throughout the lake. Water motion is multidimensional through all of the water of a lake although deep vertical mixing may be inhibited by a metalimnion barrier (Mortimer, 1974; Qu'Appelle Basin Study, 1972; Klashman et.al., 1969).

4.1.3 TEMPERATURE

Many physical, biological and chemical processes in water are affected by the temperature of the water. Increases in water temperature raise the oxygen demand of fish but decreases the solubility of oxygen thereby decreasing the capacity of the water to hold gas. The solubility of many chemical compounds increases with higher temperatures and increases the ability of plants to absorb minerals up to a maximum of about 30°C, thereafter decreasing in that ability (Brown, 1971). Temperature is a major factor in determining the effects of pollution on aquatic life. Water movements, stratification and mixing are largely temperature controlled since water is at a maximum density at 4°C and surface heating in the spring or cooling in the fall can cause overturn of lake waters. Aquatic organisms have upper and lower temperature limits for survival so alterations in water temperatures can cause changes in species composition (McNeely et.al., 1979; Klarer & Hickman, 1975; Brown, 1971; Bhagat et.al., 1970; Swenson & Baldwin, 1965; American Water Works Assoc., 1950; Born & Yanggen, date unknown).

The temperature of lake waters is a function of location and climatic regime with natural seasonal and diurnal variations. This can be altered by man through the release of thermal effluent to lake waters

or by increases in the sediment load which may increase the absorption of solar energy.

Recreation use, domestic uses and biological communities can all be affected by changes in the temperature regime of a lake's waters. Therefore, most guidelines contain recommendations that little change be made to that natural regime if the objective is to maintain current conditions (McNeely et.al., 1979).

4.1.4 pH

pH indicates the balance between the acids and bases in water, reflecting its solvent power (i.e. the possible chemical reactions on rocks and soils). It is a measure of the number of grams of hydrogen ions per litre of water. A scale of 0 to 14 is used with less than 7 being acid, 7 neutral and over 7 alkaline.

Hard water generally has high pH and soft water, low pH. High pH is usually related to increased photosynthesis and the removal of CO_2 while decompositional release of CO_2 and other organic acids causes low pH (Warry, 1978; Brown, 1971).

pH affects species composition in the aquatic environment, the availability of nutrients and the relative toxicity of many trace elements. Treatment of water supplies is also affected (McNeely et.al., 1979).

4.1.5 COLOR

Color in lake water is derived from natural mineral components and organic sources. Iron, manganese, algae, protozoa and products from decaying vegetation such as tannins, lignims and humic acid all combine to cause high coloration. The decaying vegetation polyphenolic substances are the most common source of natural water color and are

generally associated with high pH values (McNeely et.al., 1979; American Water Works Association, 1950), although this is not always the case. Many dystrophic European waters have low pH values (pers. comm. with Hickman, 1980).

Measurement of water color is either as true color (TCU), which measures only dissolved coloring compounds, or as apparent color (ACU) which is influenced by the suspended material in the sample. Water with low turbidity will, therefore, have virtually identical true and apparent color values. Apparent color measures are also known as transparency (McNeely et.al., 1979; Brezonik, 1972; American Water Works Assoc., 1950; Born & Yanggen, date unknown).

Excessive color is not generally considered to be a serious problem and it is not usually considered to be a very useful criteria to use in defining water quality, but it may impede photosynthesis by interfering with the passage of light. Guidelines are generally established for aesthetic reasons and to prevent possible staining of fixtures, food and clothes (McNeely et.al., 1979; Swenson & Baldwin, 1965).

4.1.6 TURBIDITY

Turbidity measures the degree of opaqueness produced by suspended particulate matter in a water sample. Both inorganic and organic particles such as silt, clay, organic matter and plankton may be suspended in water and affect the optical properties of it (McNeely, et.al., 1979; Smith & Addington, 1978; Beasley, 1972). Secchi disc readings are often used an an indirect measure of turbidity.

Movement of sediments from land to water is quantitatively one of the greatest causes of declining lake water quality (Beasley, 1972; Ritchie,

1972). High turbidity measurements indicate that soil is being eroded and carried into surface waters. With it, fertilizer, pesticides, plant residue and animal wastes are carried into the water (Cooley, 1976; Beasley, 1972; Born and Yanggen, date unknown). Turbidity values are usually highest during spring runoff and storm events, decreasing as flow decreases (McNeely, et.al., 1979; Meiman & Kunkle, 1967). Wave action increases turbidity along shores and in shallow sections through bluff erosion and disturbance of bottom sediments (Hickman, 1978; American Water Works Assoc., 1950; Born & Yanggen, date unknown).

High turbidity reduces light penetration thereby reducing photosynthesis and primary productivity. The number and variety of bottom organisms is also reduced along with the survival rates of eggs and alevins. Fish may become more susceptible to infection subsequent to abrasion effects and may also have difficulty finding food. Water temperatures may be raised through solar heating of the particles if those particles are dark in color, thereby having a low albedo. Dissolved oxygen levels may also be affected if there is a high organic component to the suspended sediments (Goldman, et.al., 1974; Schindler & Lean, 1974; Fast, 1973; Beasley, 1972; Ritchie, 1972; Bhagat, et.al., 1970).

While turbidity does not affect health unless related to toxic minerals, it has an important effect on visual appeal and recreational enjoyment. Levels over 5 JTU (Jackson turbidity units) are visually noticable so lower levels are desirable, as noted in table 7 (McNeely, et.al., 1979; Mechalas, et.al., 1972; Swenson & Baldwin, 1965).

4.1.7 DISSOLVED OXYGEN

The atmosphere contains 20.95% oxygen by volume. It is moderately

soluble in water with that solubility or saturation being pressure and temperature dependent. Saturation ranges from 15 mg/l at $0^{\circ}C$ to 8 mg/l at $25^{\circ}C$ at sea level (McNeely, et.al., 1979). Oxygen solubility also declines exponentially with increases in salt content (Wetzel, 1975).

Sources of dissolved oxygen (D.O.) are photosynthesis and reaeration from the atmosphere through surface turbulence. It is utilized in the oxidation of inorganic materials (eg. nitrification), the decomposition of organic matter (i.e. decay bacteria use O_2 in the breakdown of organic matter into CO_2 and H_2O), and in respiration by aquatic organisms (Warry, 1978; Davis, 1975; Wetzel, 1975; Fish, 1972; Brown, 1971; Born & Yanggen, date unknown).

As these processes of supply and utilization are strongly variable seasonally and diurnally, the levels of D.O. in freshwater are similarly highly variable. Photosynthesis is a daytime process, thereby supplying D.O. only at that time. During the night, plant respiration uses D.O. and releases CO_2. The collapse of summer algae blooms can put a great strain on D.O. supplies even while photosynthesis and reaeration are still active. During the winter months, there is little or no photosynthesis and no reaeration due to ice and snow cover but decomposition and oxidation continue, using the the D.O. supply. Winter deoxygenation tends to stimulate nutrient mobilization from the sediments into the overlying waters. A basic difference between the anoxic conditions in winter, which occur gradually, and the rapid O_2 depletion following bloom collapses in summer is that the latter can have a more significant effect on the chemical equilibrium of lake waters due to the rapidity of the change (Barica, 1974).

Low D.O. levels have a marked effect on many processes in aquatic life. O_2 requirements of fish are noticably influenced by season, temperature and activity with low levels influencing growth rates, food conversion efficiency and feeding in some species (Davis, 1975). Anoxic conditions due either to algal bloom collapses or winter conditions can cause fish kills due to suffocation. Although D.O. levels have no adverse physiological effect on man and may even be desirable for some industrial uses, D.O. must be available for fish and other aquatic organisms (McNeely, et.al., 1979; Wetzel, 1975; Bhagat, et.al., 1970).

4.2 EUTROPHICATION

Eutrophication is the natural aging process for inland water bodies. A supply of plant nutrients and sediments to the water from the surrounding drainage basin (allochthonous material) stimulates phytoplankton growth with photosynthesis and plant production in the lake (autochtonous material) progressively increasing. The increased productivity at all levels of the food chain is beneficial so long as the organic substrate does not become anaerobic. O_2 depletion occurs eventually in the eutrophication process, with the time framework being regulated largely by the form of the lake basin and the rate of decomposition of the growths of aquatic vegetation. Successional changes in the kinds of organisms inhabiting the ecosystem occur in response to O_2 depletion and changing nutrient supplies. Increased sedimentation of allochthonous and autochthonous materials ultimately culminates in the total elimination of open water and a terrestrial habitat emerges (Horstman, et.al., 1978; Vallentyne, 1974; Carleton, 1972).

'Cultural' eutrophication is the man induced process of overenrichment

of surface waters with nutrients which stimulate phytoplankton growth and species changes at an accelerated rate. Any anthropogenic changes to a lake's watershed which increases the supply of nutrients and sediment to a lake will cause some degree of cultural eutrophication (Vallentyne, 1974; Carleton, 1972).

4.3 NUTRIENTS

The condition of a lake depends largely upon the availability of nutrients and, as the level of nutrients increases, the numbers and types of plankton change leading ultimately to a eutrophic state (Bhagat, et.al., 1970). There will, however, be a limit to how large the phytoplankton populations will get with physical conditions (temperature, irradiance, turbulence, etc.) ultimately limiting further increases (Hickman, 1980).

The classical approach to water quality studies is actual measurement of nutrient and chemical concentrations over a period of time. These measured concentrations and the form of nutrient measured are the result of supply and input rates, the interconversion reactions occurring within the lake, regeneration from sediments and the rate of loss by outflow, sedimentation and organism withdrawal. Nutrient concentrations vary over time and space, influencing the distribution and abundance of aquatic vegetation which in turn are partially responsible for the changes in nutrients. The flux rates of nutrient elements are extremely flexible. A small nutrient pool turning over rapidly through interconversion reactions and regeneration can furnish the same supply of nutrients as a large pool turning over slowly. While concentration measurement is still considered to be the most accurate method for studying water chemistry, it is actually the gross quantity of nutrient supplied to the lake and the rates of converstion which are most

important rather than the concentration per se (Gachter, et.al., 1974; Brezonik, 1972; Schindler et.al., 1972; Brown, 1971; Gerloff & Skoog, 1954).

The study of nutrient retention and leakage from land is of prime importance in understanding the acceleration of eutrophication of lakes. In order to correlate nutrient concentrations, nutrient inputs and biological responses with anthropogenic causes of increased supply, it is necessary to examine the basic natural variation and the cycling behaviour for each parameter measured (Cooley, 1976; Stark, 1972; Alexander, 1970).

Several water nutrient parameters are examined in the following sections in terms of general information on cycling and form changes, environment range, common natural and man-made sources and effects of the parameter on use.

4.3.1 PHOSPHORUS

There are several hundred compounds of elemental phosphorus (P) which may be found in living cells. These compounds of P play unique and essential roles in all of the fundamental biochemical reactions of life, including photosynthesis and respiration. It is one of the major elements required for zooplankton and phytoplankton growth (Kramer, et.al., 1972; Swenson & Baldwin, 1965). In most natural occurrances in water, P atoms are fully complexed with O_2 atoms to form phosphate ions (PO_4) (Vallentyne, 1974).

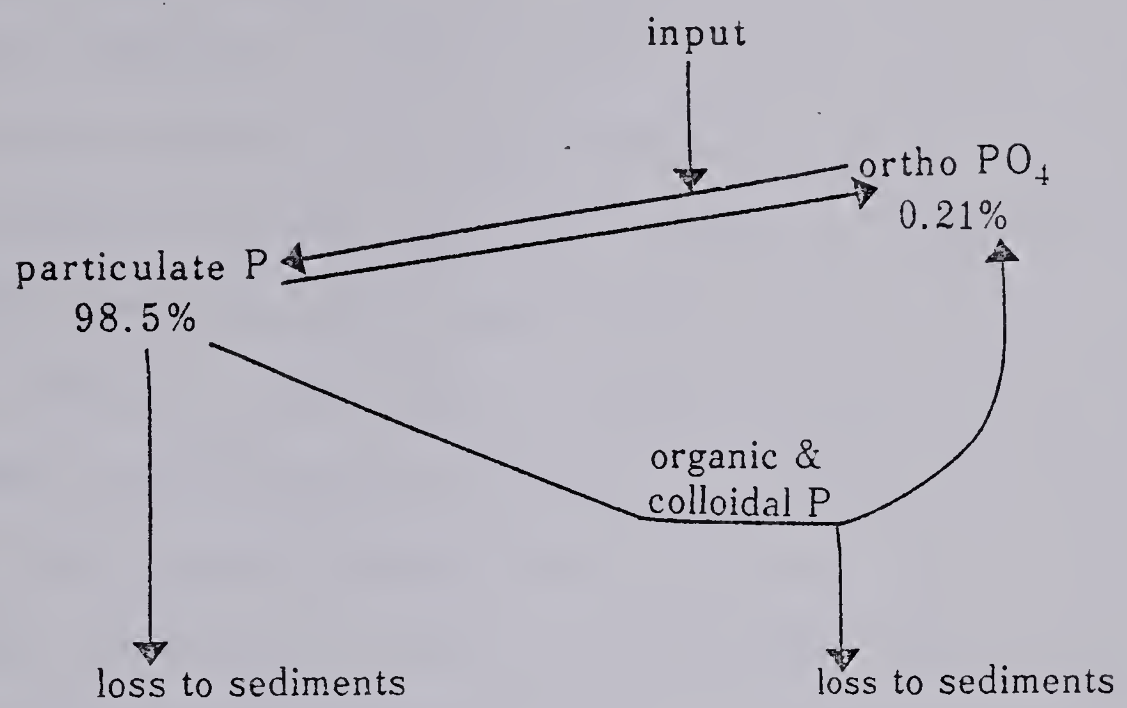
P can occur in numerous organic and inorganic forms, as dissolved or particulate fractions. Analyses of P circulation in fresh waters have shown that it has a very rapid turnover rate and is continually changing

in form due to uptake by plankton, release through decomposition, microorganism excretion and synthesis between organically bound forms and oxidized inorganic forms (Kramer, et.al., 1972).

Data for fresh water P concentrations are usually reported as total PO_4 and ortho PO_4 (soluble reactive inorganic P). Over 95% of the total PO_4 is in the particulate phase of living biota, particularly algae, in most lakes. Some of this is lost temporarily or permanently to sedimentation, and some is excreted by the microorganisms as PO_4 or as an organic P compound which is quickly converted to PO_4 (figure 22 is a representation of this highly simplified view of the P cycle). In the latter process, some PO_4 ions may react with other geochemically abundant ions, principally calcium, iron and aluminum, to form precipitates that have a low solubility in water. The only form of P which can be used by plankton is the soluble reactive fraction of ortho PO_4 which is supplied by excretion from the seston, decomposition and allochthonous inputs. As PO_4 is rapidly cycled and taken up for use, the measurable concentrations are generally very low (McNeely, et.al., 1979; Wetzel, 1975; Vallentyne, 1974).

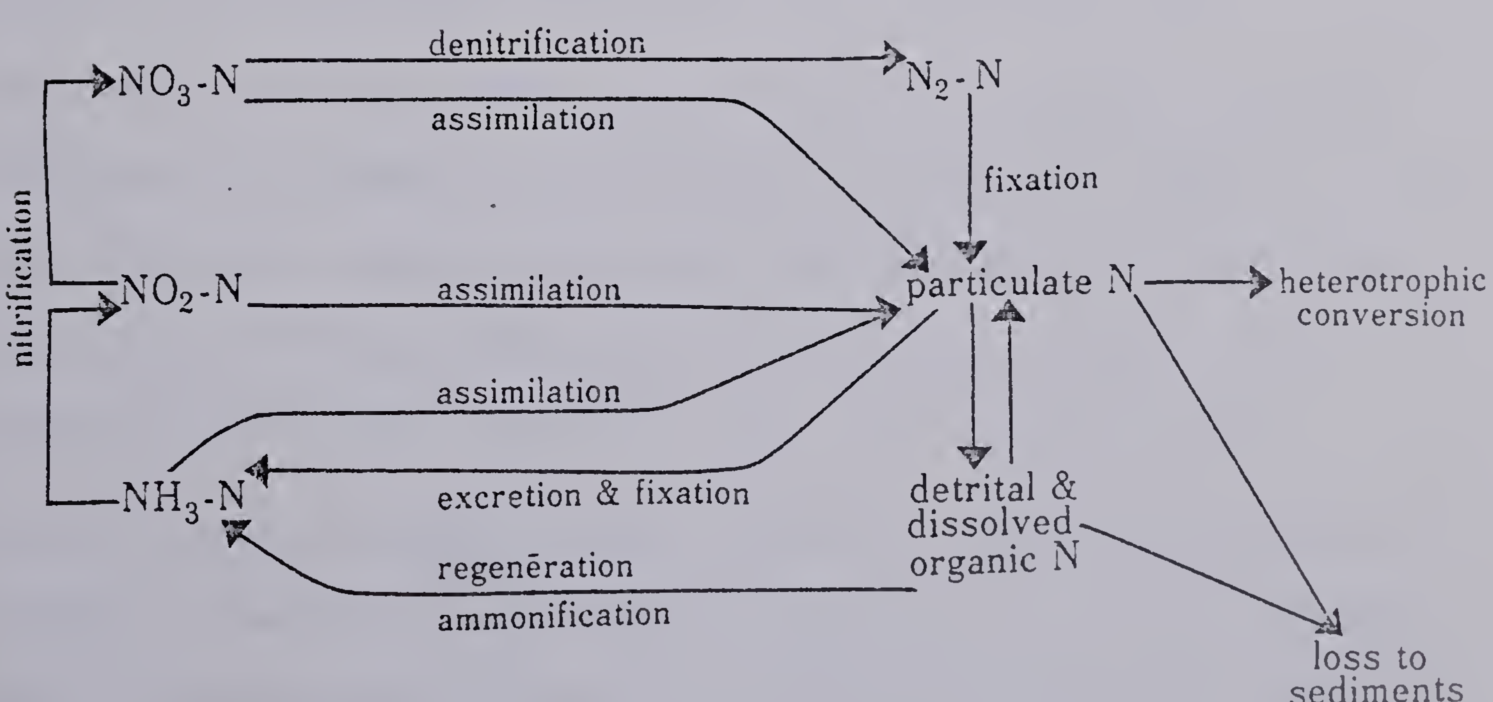
Measured concentrations of PO_4 are highly seasonally dependent. Concentrations are typically highest in temperate lakes in early spring when biological activity is lowest and winter nutrient accumulations are highest. Warry (1978b) found that in Georgian Bay, Ontario, the ratio of total particulate P to total P was at a minimum in April and a maximum in May, indicating that much of the P had been converted from the soluble to the particulate form during that time. As phytoplankton crops increase, PO_4 is rapidly depleted until there is little or no

FIGURE 22 IDEALIZED PHOSPHORUS CYCLE IN LAKES



Source: Wetzel, 1975

FIGURE 23 IDEALIZED NITROGEN CYCLE IN LAKES



Source: Alexander, 1970

detectable concentration through the summer months. During this time, ortho PO_4 is utilized within minutes of when it becomes available (Hutchinson, 1973; Carleton, 1972). During the winter months, supplies of P usually increase as organic sediments undergo bacterial decomposition. P is also released from lake sediments in winter when iron compounds, to which P is often complexed, changes in redox potential at low O_2 levels and once again becomes soluble (Osborne & Moss, 1977; Golterman, 1975; Li, et.al., 1972; Koenings & Hooper, date unknown). This is known to occur often in Alberta lakes during the winter (Hickman, 1979a; Hickman, 1979b; Klarer & Hickman, 1975). Hutchinson (1973) noted that areas in a lake with high summer phytoplankton crops often correlate well with areas where winter PO_4 levels are highest (Warry, 1978a; Warry 1978b; Findley, et.al., 1973; Brown, 1971).

It is difficult to draw clear correlations between P supplies and biological response due to the ability of phytoplankton to 'luxury' consume extra PO_4. That is, some cells have the ability to store PO_4 in excess of their immediate needs for later utilization if P should become deficient (Vallentyne, 1974; Alexander, 1970).

Since PO_4 is actively taken up by phytoplankton whenever it becomes biologically available so long as there are sufficient amounts of the other nutrients required, total PO_4 concentrations in uncontaminated temperate zone lakes rarely exceed 0.01 to 0.05 mg/l during the summer and fall months (McNeely, et.al., 1979; Ruttner, 1975).

P is an important element in soil and rocks. Leaching or weathering of rocks, especially igneous rocks, as well as soil erosion, particularly of clays high in P content, are important natural sources of P.

Soil surfaces with relatively large amounts of plant detritus in various stages of decomposition are also rich in organic P which may be leached into surface waters. Any land based activity which reduces vegetal cover and/or disturbs soil surfaces in such a way as to increase the erosion potential will also cause an increased release of P to the water. Not all of the P coming into surface waters which are adsorbed onto eroded clay is available for metabolism by algae, but in many cases the adsorption mechanism is water soluble and the P becomes biologically available (Golterman, 1973). Depending on the amount of P in soils and rocks, the land use practices, the vegetal cover and the duration and amount of runoff flow, surface drainage is often a major source of P for lakes and streams (Wetzel, 1975).

Atmospheric inputs of P through precipitation and particulate matter fallout is highly variable in time and space. It can be a significant source of P in lakes, particularly in areas affected by urban and industrial atmospheric contamination or where soil erosion and strong winds generate large amounts of dust (Wetzel, 1975; Kramer, et.al., 1972).

Dissolved organic PO_4 is produced by both living and decomposing plankton in a recycling mechanism within lake waters (McNeely, et.al., 1979; Barica, 1974; Schindler & Lean, 1974; Kramer, et.al., 1972).

Lake sediments probably serve as a net sink for total PO_4 as a result of sorption and sedimentation processes (Bannerman, et.al., 1975; Carleton, 1972). There is a one way flow of PO_4 to sediments under aerobic conditions while under anaerobic conditions, low or negative redox potentials favor solubilization of PO_4 creating a positive feed-

back cycle (Wetzel, 1975; Cooke & Williams, 1973; Fast, et.al., 1973; Carleton, 1972). Lake fertilization experiments conducted by Schindler (1974), in the Ontario experimental lakes program, indicate that sediments generally have a high affinity for P and, while return of P from sediments may occur, the net retention of PO_4 by sediments is high (Schindler, 1974; Schindler, et.al., 1972). Significant quantities of sediment may be resuspended due to wave action causing some extractable PO_4 to be released which may then become available for utilization even though it has relatively low solubility (Rogers, et.al., 1975; Wetzel, 1975). These two mechanisms together can provide small but significant amounts of PO_4 to a lake system. Muskeg flushing during wet years may also cause the movement of nutrient rich sediment into a lake system.

Man-made contributions of P are generally associated with domestic sewage, phosphates from detergents and drainage from cultivated and fertilized fields, manure piles and feedlots. Disturbance of land surfaces through poor management practices in agriculture, forestry and construction can also cause increased P contributions, as can uncontrolled drainage of swamp and muskeg areas (McNeely, et.al., 1979; Carleton, 1972; Kramer, et.al., 1972; Swenson & Baldwin, 1965).

Elemental P is toxic to man and animals but is very rarely found in this form. The more common PO_4 compounds are not usually toxic but, rather, are essential for plant growth. Water treatment difficulties can be associated with high PO_4 levels, as well as taste and odor problems. Excessive PO_4 can also cause eutrophication acceleration with its attendent algal blooms and slime development. Guidelines

on PO_4 concentrations, as listed in table 7, have been established largely to reduce eutrophication problems, to control associated domestic water use problems and to maintain aesthetically pleasing lake habitats for recreation (McNeely, et.al., 1979; Schindler, 1974; Vallentyne, 1974).

4.3.2 NITROGEN

Nitrogen is a major nutrient, the availability and utilization of which affects and sometimes controls primary production (Brezonik, 1972; Shelef & Halperin, 1969). The atmosphere is 78% N by volume, providing a reservoir of inorganic N, but the combined forms of N are those which are of interest in water chemistry. N compounds within the freshwater geocycle are present as cellular constituents, as nonliving particulate matter, as soluble organic compounds and as inorganic ions in solution (McNeely, et.al., 1979; Brezonik, 1972). The compounds of N which were examined in this study were ammonia (NH_3), nitrate (NO_3), nitrite (NO_2), organic N and total Kjeldahl nitrogen, which measures both ammonia and organic N together.

The N cycle of freshwaters is fairly well understood as being primarily a biological phenomenon but which also involves some chemical reactions. All reactions in the flow of N from organic forms, into living systems, through inorganic forms and back to organic forms are biologically mediated. The internal cycle of N in aquatic systems consists essentially of five types of reactions: N fixation by which bacteria and some blue-green algae reduce N_2 to NH_3; assimilation of inorganic N (NO_2, NO_3 and NH_3); regeneration of organic N to NH_3 (ammonification); oxidation of NH_3 to NO_2 and NO_3 (nitrification); and heterotrophic conversion of organic N from one form or organism to another (which is

how zooplankton and higher trophic levels obtain all their N requirements). Figure 23 is a flow diagram showing the various forms and conversion pathways of the N cycle in freshwaters. Turnover times for inorganic N are on the order of days or even hours with the greatest influx into organisms, chiefly phytoplankton and macrophytes, resulting from the direct assimilation of ammonia and nitrate (Brezonik, 1972; Alexander, 1970).

The seasonal cycle of N concentrations is in many ways similar to that of P. Combined inorganic N is typically highest in winter and early spring in northern temperate lakes when it is restored under ice cover by bacterial decomposition of organics. It is depleted in spring as phytoplankton crops increase. Good correlations between localities of high winter nitrate concentrations and large summer phytoplankton crops have been noted by Hutchinson (1973) (Warry, 1978b; Findley, et.al., 1973; Brown, 1971).

4.3.2.1 AMMONIA

Ammonia is found both as dissolved ammonia (NH_3) and as the ammonium ion (NH_4), both of which are readily soluble in water. Ammonia is the most reduced form of N in water, being an end product of proteinaceous organic breakdown. Ammonia may also undergo an oxidation process where a select group of aerobic bacteria obtain their energy through nitrogen oxidation. This nitrification process oxidizes labile ammonia, which tends to be lost from solution by sorption onto sediments, to nitrite and then to nitrate. A large D.O. demand is characteristic of nitrification and, where D.O. levels are somewhat low, the process may further reduce NO_3 to nitrogen gas (N_2), releasing oxygen for futher use

(Sontheimer & Kuhn, 1977; Fish, 1972). This process is not as important as direct assimilation because nitrification is active mostly when ammonia levels are artificially high and/or demand by phytoplankton is minimal resulting in a longer residence time for the ammonia form. The combined results of these processes makes ammonia the most rapidly used N source in freshwater lakes and it is typically found in low concentrations of less than 0.1 mg/l. Higher levels may be an indication of anthropogenic inputs (McNeely, et.al., 1979; Warry, 1978a; Brezonik, 1972; Fish, 1972; Alexander, 1970).

During the productive season, there is local regeneration of ammonia within the euphotic zone by excretion from algae and algae grazing zooplankton. Nitrogen fixation at temperatures higher than 5^{o}C, decomposition of organic matter, leaching of soils and erosion of clay soils with associated ammonia are other common sources of ammonia (McNeely, et.al., 1979; Barica, 1974; Brown, 1971; Alexander, 1970).

Ammonia promotes aquatic biota growth, is corrosive to copper and its alloys, is destructive to concrete and interacts with chlorine to affect water disinfection treatment. Where it is found only in the typically very low concentrations, it is not physiologically detrimental to man or animals. However, large concentrations (over .02 mg/l) reduces the oxygen carrying capacity of blood in fish and may cause suffocation (McNeely, et.al., 1979).

4.3.2.2 NITRITE AND NITRATE

Nitrite, an intermediate form of N between NH_3 and NO_3 or NO_3 and N_2, is chemically unstable in the presence of oxygen and is usually found only in minute quantities in freshwater lakes (0.001 mg/l). Presence

of nitrites indicates considerable activity in biological processes, possibly under the influence of excessive organic pollution. It is a form of N that can be used directly by plants but is toxic to man and animals and should not exceed concentrations of 1 mg/l (McNeely, et.al., 1979).

Nitrate is a final oxidation product of N containing matter in the nitrification process and is the principal form of combined N in lakes. This highly soluble ion is the most stable form of combined N. It is used directly by plankton, thereby stimulating plant growth (McNeely, et.al., 1979; Schindler, 1974; Brown, 1971).

High nitrate concentrations result from organic matter contamination and can cause reduced oxygen carrying capacity in the blood of man and animals. This can contribute to methemoglobinemia or blue babies so concentrations greater than 10 mg/l are considered to be unsafe (McNeely, et.al., 1979; Swenson & Baldwin, 1965).

4.3.3.3 AMMONIFICATION

This process is the reverse of assimilation, with organic N being returned to inorganic N as ammonia. It involves the bacterial decomposition of soluble organic N and organic detritus, the excretion of ammonia and amino acids by zooplankton feeding on phytoplankton and detritus and direct autolysis after cell death. The latter may account for 30-50% of the nutrients released from plant and animal matter (Brezonik, 1972).

4.3.3.4 NITRIFICATION & DENITRIFICATION

Nitrification has been described in section 4.3.3.1 as the oxidation of ammonia, through nitrite to nitrate.

Denitrification reactions reduce nitrate through nitrite to molecular N (N_2). A simultaneous assimilatory reduction to ammonia and organic N occurs, which can be significant in certain conditions. That portion which is reduced to N_2 is lost to the internal cycle as it is a form which is not utilized by most organisms and must be re-introduced to the lake through nitrogen fixation (Brezonik, 1972).

4.3.3.5 NITROGEN FIXATION

N fixation converts N gas from the air into biologically useful nitrate and ammonia. It is generally considered to be an adaptive process used by organisms only when the supply of N in lake waters is depleted. Although it is not strictly confined to nutrient depleted waters, it is primarily a late summer phenomena in temperate lakes, such as Skaha Lake, B.C., with peaks in fixation coinciding with troughs in nutrient concentrations (Findley, et.al., 1973). N fixation has a small overall contribution of about 7% of the annual N budget in Lake Mendota, Wisconsin (this varies greatly from lake to lake), but does allow nuisance blue-green algae blooms when other forms of phytoplankton cannot compete efficiently (Torrey & Lee, 1976). N fixers include a number of blue-green algae, all photosynthetic bacteria, select aerobic and anaerobic bacteria, legume root nodules and nonleguminous root nodulated plants such as the alder tree. Some 85% of N fixation in lakes is by many genera of blue-green algae (Torrey & Lee, 1976). These N fixing algae tend to bloom only in late summer after blooms by other algae. The process requires large amounts of energy which is later released in a form which cells cannot use. Hydrogen is also used in the process (Hutchinson, 1973; Brezonik, 1972; Wiedeman, 1970).

N and its compounds are ubiquitous in the biosphere. A major source of N compounds for phytoplankton assimilation is through erosion of soil and igneous rocks. High ammonia concentrations correlate well with alkaline soils high in clay content (Brezonik, 1972). Both surface drainage and groundwater sources are important (McNeely, et.al., 1979).

N is taken up in the inorganic form by organisms and released from both living and decomposing plankton as dissolved organic N, creating internal recycling (Barica, 1974; Kramer, et.al., 1972).

Release of N from sediments due to burrowing animals, decomposition of organic N to ammonia and its diffusion to overlying water and desorption of ammonia from clays and other sorbents in the sediments provides a minor amount of N to lake waters. Lake sediments are, however, a net sink for nitrogen (Brezonik, 1972).

Rainwater contains spacially and temporaly variable quantities of N which can be a significant source, depending on meteorological conditions including the prevalence of electrical storms, the location of industrial and urban outputs and prevailing wind patterns (Wetzel, 1975; Brezonik, 1972). Most precipitation contains many nutrients.

Cultural sources of N include agricultural fertilizer and animal and human wastes (Brezonik, 1972).

4.3.4 SILICA

Silica (Si) is a nutrient which is found in most natural water. It occurs as either dissolved silicic acid or as particulate silica which is relatively unreactive chemically, being insoluble in most waters. It usually occurs in the colloidal state. Diatom require silicate

for wall formation. Certain green algae (eg. Cladophora glomesata) require it for correct wall and septa formation and Chrysophycean algae use it to form silica scales (Round, 1973). Silica is usually regenerated in the autumn and winter when diatom decomposition occurs, or when planktonic crustaceans feeding on diatoms reject the frustule (Wetzel, 1975; Fast, et.al., 1973; Brown, 1971).

Concentrations of silica in lakes is usually less than 5 mg/l but a range of 1 to 30 mg/l is not uncommon (McNeely, et.al., 1979). Silica tends to accumulate in the hypolimnion of stratified lakes along with other nutrients such as N and P (pers. comm. with Hickman, 1980). Silica is dissolved from most rocks and is leached most easily from sand, quartz, feldspar, sedimentary rocks and clay minerals. Sources of silica are primarily natural (McNeely, et.al., 1979), but fly ash also containes much Si.

Boiler scale and deposits on the blades of steam turbines may affect use of water with high silica concentrations when it is found in combination with calcium and magnesium. However, no guidelines have been established as silica is not detrimental to health or aquatic organisms (McNeely, et.al., 1979; Wetzel, 1975; Swenson & Baldwin, 1965).

4.3.5 IRON

Iron (Fe) is an essential micronutrient which appears to play a significant role as a growth limiting nutrient (Shelef & Halperin, 1969). The cycle of iron is biogeochemical in nature and is regulated largely by seasonal and spatial variations in oxidation and reduction states which are mediated by seasonal variations in photosynthetic and bacterial metabolism. Both the ferrous (Fe^{2+}) and the ferric (Fe^{3+})

forms are found in water, with occurance as ferric hydroxide in particulate and colloidal form and as complexes with organic compounds (eg. hydroxo-phosphate) being most common (Wetzel, 1975; Bortleson & Lee, 1974). The mobile ferrous ion is present under reducing conditions but is oxidized to the less mobile form and precipitated out of solution as the ferric ion when exposed to air (Warry, 1978a; Golterman, 1975; Li, et.al., 1972; Koenings & Hooper, date unknown).

Aerated surface waters generally have concentrations of iron of less than 0.5 mg/l. Acid waters and groundwaters have much higher concentrations (McNeely, et.al., 1979).

Iron can be derived from many rocks and soil types including igneous, sedimentary and metamorphic rocks and sulphide ores. Precipitation can transport some iron, particularly in areas of coal mining or coal use. Corrosion of iron and steel also contributes iron to waterways (McNeely, et.al., 1979).

Some iron in waters is good nutritionally but high concentrations impart an objectionalbe taste to the water, causes high coloration and stains clothing and fixtures. Excessive levels (over 20 mg/l) can be toxic to plants (McNeely, et.al., 1979; Swenson & Baldwin, 1965; American Water Works Assoc., 1950).

4.4 MAJOR IONS

The ionic composition of lake water is made up largely of four major cations (calcium, magnesium, sodium and potassium) and four major anions (carbonate, bicarbonate, sulfate and chloride) which together constitute the total ionic salinity of the water. They are generally found in small quantities but are none the less biologically important.

The chemical composition of open lakes is governed primarily by inputs from surface drainage and atmospheric contributions balanced by outflow, loss through sedimentation and removal of organisms from the system. Measurements of these ions may be made in a number of ways including: individually, as has been done for four of the eight major ions in this study; as total amounts by measuring conductivity or total dissolved solids; or in their effects on hardness and alkalinity (Wetzel, 1975).

Dissolved salts are derived primarily from overland flow contributions with high levels indicating soil loss. The types of salts in solution depend on the local geology and soils in the drainage basin. Some dissolved salts are regenerated from the sediments through bacterial action (Cooley, 1976).

The concentration of salts decreases when plant growth is high, so seasonal trends can be expected. The fertility of a lake is reflected in the concentration of salts available, with positive correlations between it and average standing crops of plankton (Brown, 1971; Rawson, 1951; Born & Yanggen, date unknown).

Drastic changes in ion concentrations interfere with osmotic pressure and exchange of ions by the cell membranes of aquatic life (Bhagat, et.al., 1970). Consistently high concentrations cause taste problems for domestic water supplies and have a laxative effect on users (McNeely, et.al., 1979; Swenson & Baldwin, 1965).

4.4.1 SPECIFIC CONDUCTANCE

Conductance is a measure of the ionic concentration in a water sample based on its resistance to a current of electricity. It is expressed

as μmhos cm^{-1}. As it is temperature dependent, a correction to a standard temperature of 25°C is made. There is greater resistance in pure waters with low salinity and changes in the conductance reflect changes in the major ionic concentration in the water (McNeely, et.al., 1979; Wetzel, 1975; Swenson & Baldwin, 1965).

Conductance is often used as an indirect measure of total dissolved solids with correlations between the two being so good that guidelines for total dissolved solids are thought to be sufficient (McNeely, et.al., 1979).

4.4.2 TOTAL DISSOLVED SOLIDS

Total dissolved solids (TDS), also called total dissolved salts or residue, is an index of inorganic materials dissolved in a sample. Anything over 1000 mg/l is considered to be brackish (Cooley, 1976).

4.4.3 HARDNESS & ALKALINITY

For this study, both hardness and alkalinity have been expressed in terms of the precipitated $CaCO_3$ (calcium carbonate) as is customary in North America since both are usually caused almost entirely by compounds of calcium and magnesium with calcium being most common. Magnesium is a conservative ion, exhibiting only minor changes within a lake while calcium is more dynamic and is most likely to respond to changes in the environment (Wetzel, 1975).

Hardness retards soap lather, causes wear in fabrics, roughens hands and cloths and causes scale to form on pipes and boilers. Hardness in water has been shown to be desirable for health reasons and is preferred for irrigation use. A wider variety of animal life is supported by hard water than by calcium deficient soft waters which often originate

from acid peaty soils. Waters with ions derived from carbonate bedrock are typically hard with soft water being found in areas of igneous rocks (McNeely, et.al., 1979; Brown, 1971; Swenson & Baldwin, 1965). Table 8 outlines the range of hardness which is recommended for use in Canada. Suggested limits for hardness in water vary dramatically from place to place and, in some areas, very hard water is quite acceptable.

Alkalinity is a measure of a water's capacity to neutralize an acid. It is normally interpreted as hydroxides and as the anions HCO_3^- and $CO_3^=$. Concentrations increase with lower discharges but rarely exceed 500 mg l^{-1}. Sudden variations can be detrimental to the aquatic environment. High alkalinity is associated with excessive hardness and its problems for use and can also cause gastro-intestinal irritation. Measures of over 90 usually support high productivity of plants and fish. Low alkalinity can cause corrosion of pipes and generally supports a low rate of plant and fish production (McNeely, et.al., 1979).

TABLE 8 HARDNESS RANGE RECOMMENDED FOR CANADA

0 - 30 mg l^{-1} $CaCO_3$	.... very soft
31 - 60 mg l^{-1} $CaCO_3$	.... soft
61 - 120 mg l^{-1} $CaCO_3$	.... moderately soft
121 - 180 mg l^{-1} $CaCO_3$	.... hard
over 180 mg l^{-1} $CaCO_3$	.... very hard

source: McNeely, et.al., 1979

4.5 LIMITING NUTRIENT CONCEPT

This concept is based on the idea that in a system with a more or less fixed organism composition, one material essential for biotic production will be used up before the others and will limit further productivity. This has the potential of being very important in abating the deterioration of aquatic environments where it is possible to identify and control a limiting nutrient. P, N and C (carbon) are generally considered to be the most likely nutrients which could be limiting but the limiting factor will vary from region to region and over time. P is most often considered as the most probable limiting nutrient, particularly in lakes which tend naturally to be oligotrophic, while eutrophic lakes are more likely to be N limited (Carleton, 1972). It is unlikely that C will be limiting in most instances as C enters lake waters readily from atmospheric CO_2 (Ernst, 1977; Wetzel, 1975; Carleton, 1972; Kramer, et.al., 1972; Schindler & Lean, 1972; Schindler, et.al., 1972).

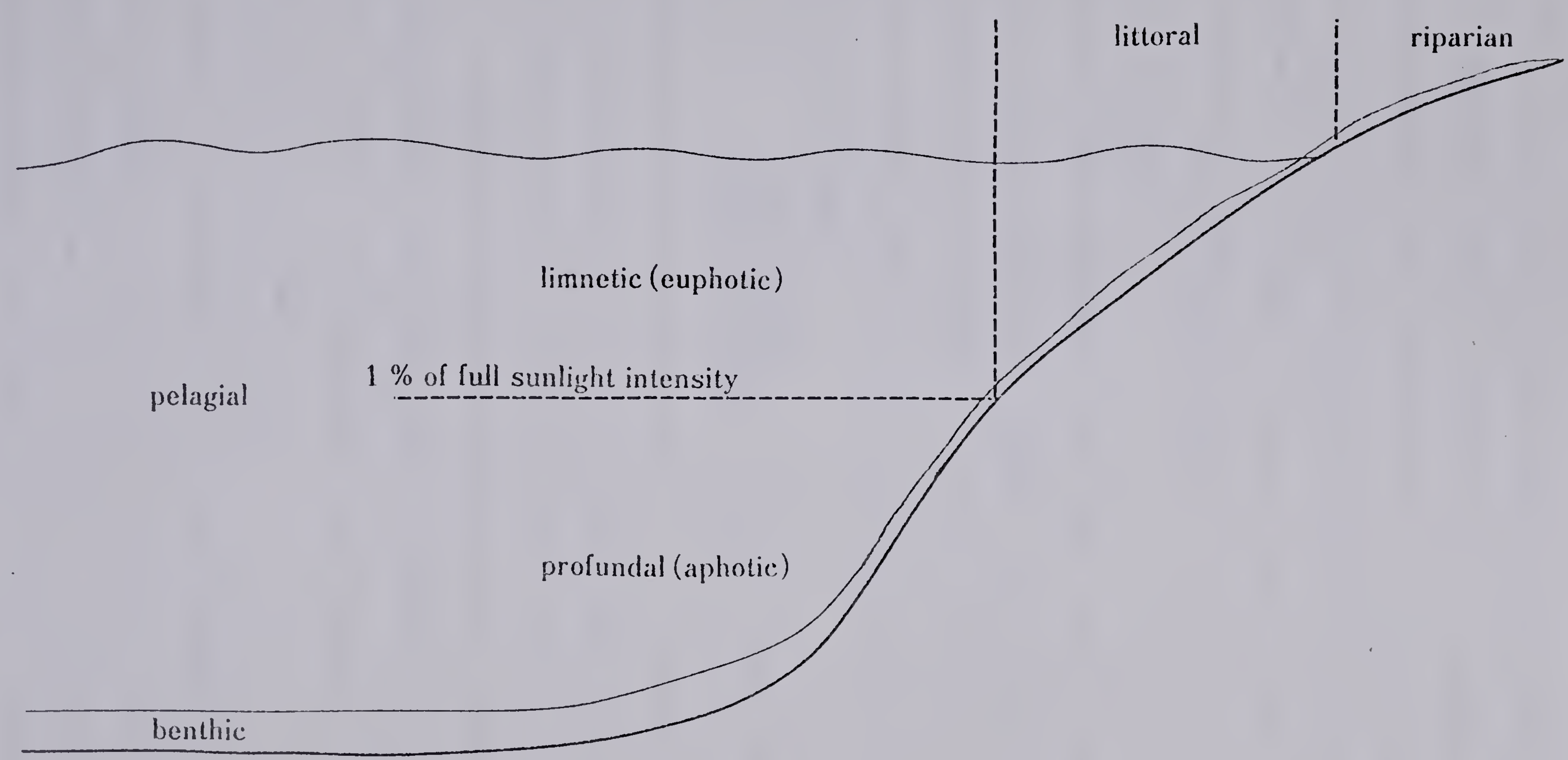
In attempting to use this concept in practice, one must be very careful not to oversimplify the situation if positive results are to be obtained. In some cases, the first nutrient which is found to be limiting may be a result rather than a cause of phytoplankton blooms.

4.6 AQUATIC BIOTA

Water quality is influenced by the plants and animals growing in it and they, in turn, are modified by the condition of the water. The biology of any surface water provides a living expression of the chemistry and physics of the water (Fish, 1972).

Figure 24 is a representation of the major zones in a lacustrine

FIGURE 24 MAJOR LACUSTRINE ZONATION



Source: Wetzel, 1975

environment. These zones will be referred to in this section on aquatic biota. While it is not within the scope of this study to detail the effects of nutrient loading on aquatic biota in Sturgeon Lake, a resume of general effects will facilitate the analysis of potential use problems relating to the inflow of allochthonous materials to the lake. The following is a summary of various aspects of the autotrophic biological productivity in temperate lakes.

4.6.1 PRIMARY PRODUCTION

Primary production is the quantity of new organic matter created by photosynthesis on which organic life depends. The following equation from Wetzel (1975, pg.321) represents an oversimplification of the process of photosynthesis which converts inorganic matter to organic matter through use of energy:

$$6CO_2 + 12H_2O \xrightarrow[\text{pigment receptor}]{\text{light (energy)}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

The total amount of organic material created from incoming solar energy is called gross primary production. Net primary production is the 40-50% of new organic material left after losses. These terms may also be applied to the equivalent amount of stored energy represented by the organic material and is the energy base on which all the rest of aquatic life (i.e. other than photosynthesizing organisms) exists (Ernst, 1977; Wetzel, 1975; Likens, 1973).

There are a variety of environmental factors which regulate net primary production including: incident solar radiation, nutrient availability, turbidity, mixed layer depth, temperature, sedimentation and primary consumption by grazing zooplankton and benthic invertibrates (Ernst, 1977; Bannister, 1974; Fast, 1973; Likens, 1973; Carleton,

1972).

Major temporal and spatial differences in primary production rates are characteristic of temperate lakes. Maximum rates are typically in mid-morning in shallow waters and about mid-day in waters of 2 meters or more (Anderson, 1974). Seasonal peaks are generally in early June and late September with a winter minimum and an early summer trough (Glooschenko, et.al., 1974a; Glooschenko, et.al., 1974b). This pattern has also been observed in several Alberta lakes (Hickman, 1979a; Hickman, 1979b; Hickman & Jenkerson, 1978).

Standing crop or biomass is the weight of all living material in a unit area at a given time (Wetzel, 1975). It is essentially a balance of organic material on hand and is, in fact, the objectionable feature aesthetically in most lakes, rather than production which does not account for losses (Schindler & Lean, 1974; Rawson, 1953).

4.6.2 PHYTOPLANKTON

Phytoplankters are the plant portion of the free-water community. Algae are the dominant form of pelagic phytoplankton and they are also important in the littoral zone. Phytoplankton include a large number of species of algae that coexist and show a seasonal succession of dominant species. They are small, often microscopic, plants which are subject to distribution through water movement as their powers of locomotion are limited or nonexistent (Wetzel, 1975; Brown, 1971). Phytoplankton are important in the photosynthetic supply of new organic matter and constitute the base of most food chains, especially as food for fish (Wiedeman, 1970; Brown, 1955; American Water Works Assoc., 1950).

The most common forms of algae include: single-celled green plants; specialized single-celled desmids and diatoms; colonial forms which are massed together in a jelly sphere and filamentous formations of long chains of cylindrical cells in a tangled mass of slime (Brown, 1955). There are several types of algae making up this large and incongruous group which are found in various quantities in freshwater lakes.

The common phytoplankters include members of the Cyanophyta (blue-green algae). If conditions are correct, these algae produce massive growths called 'blooms' particularly in eutrophic lakes. They are common in many Alberta lakes with the genera Anabaena, Aphanizomenon, Microcystis, Gromphosphaeria, Lyngbya, Oscillatoria and Gloeotrichia being important. Many blue-green algae are inedible, possibly due to their shape, but also due to the copious amounts of mucilage produced. Some species have strains which produce toxins. These, if in sufficient concentrations, can kill fish, ducks and livestock as well as humans. This group of algae also possesses the ability to fix atmospheric nitrogen. Most planktonic blue-green algae attain maximum population size during mid to late summer (Horstman, et.al., 1978; Wetzel, 1975; Carr & Whitton, 1973; Findley, et.al., 1973; Hutchinson, 1973; Round, 1973; Carleton, 1972; Wiedeman, 1970).

The diatoms (Bacillariophyta) are another important group of algae in eutrophic waters, with the genera Asterionella, Fragilaria, Stephanodiscus, Synedra and Cyclotella being most important. They may be either unicellular or colonial in form and tend to dominate in winter and spring algal blooms. They have specialized silicon dioxide cell walls and may, therefore, be limited in growth by a shortage of

silica (Bailey-Watts, 1976; Wetzel, 1975; Wiedeman, 1970; Happey, 1970; Lund, 1950; Meloche, et.al., 1938; Pearsall, 1923).

Green algae (Chlorophyta) form a large and morphologically diverse group of algae common to fresh waters (Wetzel, 1975). They have a high nutritional value and are used as a food source in some parts of South America, as well as being used as fertilizer on a world scale (Wiedeman, 1970).

Yellow-green algae (Xanthophyta) are mostly associated with substrata and are commonly epiphytic on larger aquatic plants. Golden-brown algae (Chrysophyta) are mostly unicellular algae that can form an important component of the phytoplankton, especially in oligotrophic waters. However, species such as Ochromonas and Dinobryon grow well in eutrophic lakes, particularly when nutrients become depleted. Euglenoid algae, dinoflagellates and cryptophycean algae are all types of algae that are relatively uncommon but may be locally important (Wetzel, 1975; Carr & Whitton, 1973).

The various species and genera of algae have seasonal cycles and, where several species inhabit the same lake, there is generally an out-of-phase balance in their respective bloom and collapse fluxes. Generally, in a lake such as Sturgeon Lake, winter growth is low, with flagellated algae dominating under the ice cover. A spring maximum of diatoms is followed by a green and blue-green bloom with the blue-green bloom lasting into the autumn. A small second diatom bloom may occur before the winter minimum. Each bloom cycle will collapse when nutrient availability drops and/or self shading inhibits photosynthesis. These seasonal changes tend to be characteristic consis-

tently over a period of years, unless outside influences disrupt the cycle. Nutrient loading from the drainage basin can be sufficient to upset the species succession cycle (Wetzel, 1975; Brown, 1971).

Algae are extremely efficient at absorbing elements in very dilute solutions from the water and measures of nutrient supply vary as algae are moved about in the water. Some species are able to 'luxury' consume extra nutrients beyond their immediate needs for use when there is a nutrient deficiency (Hutchinson, 1973; Gerloff & Skoog, 1954).

Temperature, light intensity, water clarity and nutrient supply are the principal factors involved in algal growth (Reeves, et.al., 1975). The tolerance of different groups to variations in temperature may affect succession. Concentrations of algae generally decrease with depth, as solar insolation penetration decreases, and inhibition of light penetration by suspended sediment will cut down productivity. In lakes which are well mixed to maximum depth this vertical distribution of phytoplankton is not as well developed (Hickman, 1979a; Hickman, 1979b). Inorganic macro and micro nutrients as well as dissolved organic matter are important nutrient sources for algae. Luxuriant growths of algae are often considered to be visual evidence of a large nutrient supply (Reeves, et.al., 1975; Wetzel, 1975; Qu'Appelle Basin Study, 1972; American Water Works Assoc., 1950).

Although some algae is important as an oxygen and food source, excessive amounts are detrimental. Consistent excessive die off of algae contributes to bottom deposits leading to oxygen deficiencies. Large amounts of bottom deposition may also interfere with gamefish spawning and organism growth. Some species of algae may be controlled by

grazing by zooplankton and fish. However, the forms more indicative of eutrophication, such as blue-green algae, are not grazed by many predator species, so that ultimately, the less desirable groups of algae become dominant. Large algae blooms are aesthetically unpleasant and degrade recreational areas (Carleton, 1972; Kappe, 1972; Sheffield & Kaleel, 1970; Rawson, 1956).

4.6.3 PHYTOBENTHOS AND MACROPHYTES

Phytobenthers include all of the floral organisms which live on or are closely associated with a solid/liquid interface in an aquatic environment (Holme & McIntyre, 1971). Where planktonic refers to the open water community, benthic refers to the community which lives on the bottom or on the plants which live on the bottom of a water body. As such, the benthic community is notably affected by the morphometry of a lake basin while the planktonic community is affected to a much lesser degree, except where open water is severely limited as in a small pond or marsh. In a habitat such as that, the benthic algae may constitute a major proportion of the algal biomass. Benthic algae may account for over 90% of all algae species (Round, 1964, pg.139). The benthic community is commonly subdivided according to the substrate on which the subcommunity lives. These subcommunities are generally classified as the epipelic, epiphytic, metaphytic and epilithic associations (Wetzel, 1975; Round, 1973; Holme & McIntyre, 1971; Round, 1964).

The epipelic group are flora which are mostly motile, moving in or on bottom sediments of sand, silt and organic matter. This subcommunity consists primarily of motile diatoms but filamentous or coccoid Cyanophtya, bacillariophyta, dinoflagellate and euglenoid flagellates are also found (Hickman, 1978; Holme & McIntyre, 1971). Epipelic flora,

due to its association with bottom sediments, is slower to react to changing chemical regimes in lake waters than plankton is (Round, 1964). Hickman (1978) found in a study of five eutrophic prairie-parkland lakes in Alberta that mean epipelic standing crops expressed as a percentage of mean phytoplankton standing crops ranged from 2.5 to 72.2%. It is thought that due to the depth of Sturgeon Lake and the relatively poor water clarity in most locations, that the importance of epipelic algae would be closer to the former figure.

Epiphytic algae grow on macrophytic plants and are mostly non-motile. In temperate regions, the terrestrial epiphytic flora is relatively poorly developed and this is reflected in the seeming paucity of aquatic epiphytic species in these areas (Round, 1964).

Metaphytic algae are composed of a mixture of algal species which are found between benthic macrophytes but are neither clearly associated with them nor free-floating. This subcommunity can be an important component of the littoral biomass in some lakes (Round, 1964).

The epilithic algae are those which grow on rock and stone surfaces. Like the epiphytic group, they are chiefly non-motile. This subcommunity of algae must be quite insignificant in Sturgeon Lake as there are very few areas with a rocky substrate.

Aquatic macrophytes (Rhizobenthos) are the macroscopic forms of the phytobenthos and may be emergent, submersed or floating-leaved. Most of these plants appear to have evolved from terrestrial plants, particularly the angiosperms. They colonize in the littoral zone in soils from about a half meter above the lake level on dry land to a water depth of between 3 and 10 meters. The rooted emergent macrophytes in

shallow, nutrient rich water and sediments have a close to optimum habitat with a liquid medium for roots and exposure to air, so biological productivity is very high. The submersed portions of macrophytes provide a surface area that is usually colonized by epiphytic microflora. Littoral macrophyte productivity can be a major source of organic matter in a lake (Wetzel, 1975; Likens, 1973; Brown, 1971).

All of the phytobenthic communities may play an important part in the early and final stages of eutrophication, eventually constituting the majority of the primary producers in the lake basin. Therefore, measures of productivity and trophic status based on phytoplankton alone are restricted and, unless approached cautiously, may be incorrect (Wetzel, 1975; Likens, 1973).

4.6.4 ZOOPLANKTON & FISH

There is also an extremely diverse character to the animal components of fresh water systems. The free floating animal component, zooplankton, is represented primarily by rotifers and two subclasses of the Crustacea (Wetzel, 1975).

Fish are also an important part of lake systems. Fish populations can modify flora through feeding and disturbance of sediments but, more often, their populations shift in response to the habitat conditions. As the highest trophic level in lakes and an important food and recreational resource for man, this can have far-reaching effects. The growth of fish is enhanced in the early stages of eutrophication but ultimately, the more desirable species for use by man are eliminated in favor of coarser fish which have adapted to eutrophic conditions (Wetzel, 1975). In this study, the condition of the fish population

of Sturgeon Lake is used primarily as an indicator of what the condition of the water is and how it is changing.

4.6.5 CHLOROPHYLL a

Due to limitations on the availability of biological measurements, the only aspect of the biotic environment of Sturgeon Lake which was sampled was chlorophyll a. This was supplemented with field observations of macrophyte growth and the extent and timing of algal blooms. While it is, admittedly, a simplistic view of the biological metabolism of the lake, it does provide an indication of the amount of primary productivity occurring.

Chlorophyll a is ubiquitous in green plants, being the main photosynthetic pigment in all oxygen-evolving photosynthetic organisms, and may comprise 4-12 % of the ash free dry weight of phytoplankton (McNeely, et.al., 1979). As such, it is often used to estimate plant biomass (Wetzel, 1975; Gachter, et.al., 1974; Schindler, 1974; Arvesen, et.al., 1971; Alexander, 1970).

As a plant ages and dies, its chlorophyll degrades to pheophytin, a brown pigment. A correction in the biomass estimate must be made for the pheophytin present in a sample (McNeely, et.al., 1979; Moss, 1967a; Moss, 1967b).

Variations in chlorophyll a are often associated with changes in temperature and nutrient availability. Eutrophic waters may contain anywhere from 10-100 mg m^{-3} and, while there are no quality guidelines in Canada for chlorophyll a, levels over 100 mg m^{-3} are considered to be excessive (McNeely, et.al., 1979; Sager & Wiersma, 1975). Measurements of maximum summer concentrations in Alberta lakes range

from 5.3 mg m^{-3} to 241.2 mg m^{-3} (Hickman, 1980). High concentrations indicate massive aquatic plant growth which is limiting to recreational activities (Dillon, 1975; James & Lee, 1974; Arvesen, et.al., 1971).

4.7 ELEMENT SOURCES

The quality of water bodies depends mainly on the nature and relative contributions of water source areas (Fish, 1972). As Dillon and Rigler (1975, pg.1520) pointed out, "The terrestrial and aquatic portions of any watershed are inherently linked with the gravitational movements of minerals in drainage waters flowing from the land to the water as the major terrestrial-aquatic linkage" and that "any alteration in a watershed ultimately affects the lake." Contributions of minerals and nutrients to a lake result in changes in the quality of the lake waters which often causes greater concentrations of weed and algae growth, undesirable changes in fish and wildlife populations and a general degradation of the aquatic environment and its aesthetic quality. Concern over accelerated eutrophication has stimulated the need for the measurement and monitoring of inputs from various sources so that it will be possible to forecast the results of different land management plans and control sources, thereby retarding eutrophication (Cooley, 1976; Qu'Appelle Basin Study, 1972). It is also possible, in some cases, to reverse the eutrophication process (Fast, 1973; Fast, et.al., 1973; Björk, 1972a; Björk, 1972b; Björk, et.al., 1972) but this is generally a very expensive proposition and is not feasible at present for Sturgeon Lake.

Natural nutrient input to a lake is a function of such factors as drainage basin geochemistry, drainage basin size, hydrology and precipitation

patterns. This is then modified anthropogenically by land use patterns and population characteristics (Brezonik, 1972).

Many studies have been conducted which examine anthropogenic effects where they enter a water system at a particular point (eg. sewage or industrial outflow pipes). In point source studies, it is relatively easy to determine changes in the receiving water's chemistry and attribute it directly to the causitive factor. It is more difficult to ascertain variations in water chemistry caused by non-point sources and virtually impossible to trace the differences conclusively to a particular cause. Non-point sources include such things as: forest runoff, waterfowl and wild animal wastes, marsh drainage, precipitation and atmospheric inputs, erosion of land surfaces, agricultural crop-land drainage, livestock and pasture land runoff, domestic septic tank subsurface drainage, recreational and boating wastes, natural ground-water inputs and internal recycling of nutrients within the lake (Cooley, 1976; Loehr, 1974; Brezonik, 1972; Sheffield & Kaleel, 1970). Until recently, these non-point sources were assumed to be relatively unimportant to the nutrient budget as a whole but it is now considered to be pertinent to discuss the probable magnitudes of the inputs and possible means of controlling them. A generally accepted method of doing this is to take samples from sites near the various sources and estimate the relative nutrient contributions by correlating the results with site factors (Sheffield & Kaleel, 1970).

4.7.1 FOREST RUNOFF

Undisturbed forest and meadow rangeland may serve as one of the better indicators of drainage constituents under natural conditions (Loehr,

1974; Stark, 1972). These areas are generally quite efficient in terms of nutrient retention, but since forests vary greatly in terms of species composition, drainage condition, et cetera, the nutrient retention also varies greatly and forest runoff may not necessarily be the best conditions possible.

4.7.2 WATERFOWL

There is some evidence which indicates the waterfowl sometimes make a significant contribution of nutrients to lake waters (Cooke & Williams, 1973). Generally, waterfowl have more of a cycling effect than a contribution effect since lake waters supply their food as well as accept their wastes. It can become a significant source, though, when a large migratory population uses a lake as a staging area.

4.7.3 MARSH DRAINAGE

Swamp and marshlands in the drainage area of a lake may be of major importance in the nutrient regime of the lake. During low flow periods, they will filter out sediments and trap nutrients before they reach the lake. However, during high flows, these trapped nutrients and sediments may be released from the wetlands and contribute to the nutrient budget of the lake. Quantitative information on this nutrient source is unavailable at this time (Gorski & Rybak, 1974; Born & Yanggen, date unknown).

4.7.4 ATMOSPHERIC INPUTS

Atmospheric contributions to the nutrient budget of a lake include impurities in precipitation, dry fall-out and airborne litterfall.

Precipitation usually contains impurities which are derived from earth and ocean surfaces and are later washed out of the atmosphere. Gases

such as CO_2, N and O are dissolved in rain water and it may also contain some dissolved salts. The amount and type of elements in the air varies greatly over time and space and with prevailing wind patterns. The amount of pollution washed out of the air may be negligible in areas which are not dusty or located downwind of source areas. Dust may fall directly into surface waters or be washed from the stems of emergent vegetation, dams and retaining walls where it may have accumulated during dry, dusty weather (Gorski & Rybak, 1974; Loehr, 1974; Hutchinson, 1973; McKay, 1973; Fish, 1972; Brown, 1971).

Airborne litterfall of leaves and pollen are considered to contribute significant inputs of organic matter to streams and along wooded shores but their role in terms of total lake budgets is unknown (Gorski & Rybak, 1974).

4.7.5 SOIL EROSION

Erosion of soil surfaces can contribute large amounts of sediment, organic and inorganic compounds to a lake system via surface runoff. Surface runoff will carry with it in suspension or solution any particles or chemicals which are mobile so long as they do not over extend the ability of the runoff to do work. That is, it will move with it anything that it is capable of moving (Brown, 1971).

Organic and inorganic constituents are released at varying rates from all soils and exposed geological formations through the natural weathering of rocks and minerals, and the leaching and oxidation of organic matter. The geology, soil types and topography are important determinants in establishing what the condition of surface runoff will be (Loehr, 1974).

Porous soils are subject to high nutrient leaching. Clay soils may contribute more suspended sediment and nitrates, chloride or sulphate, depending on the type of clays present and the ability to sorb various ions and organic compounds. Runoff from peat and woodland areas tends to be acidic and high in soluble organic matter (Moore, 1978; Fish, 1972; Sheffield & Kaleel, 1970).

The chemistry and erodability of rock surfaces will affect what materials will be carried in solution and suspension, due to chemical and mechanical weathering respectively. Lakes located in areas with soft bedrock tend to have high mineral contents while those in hard crystalline rock areas have low TDS. Lakes on glacial drift are more prone to have high TDS values (Fish, 1972; Rawson, 1960; Rawson, 1951).

Soil condition and vegetation cover will affect the erodability of a soil surface, as will seasonal ground condition. Snowmelt and precipitation runoff from frozen ground in the spring can be a major source of sediments and nutrients. Wind generated wave action may cause significant erosion of bluffs and shorelines, particularly when vegetation has been removed. Any activity which removes protective vegetation cover, reduces infiltration rates for soils, or increases the erosion potential of an area will increase the sediment load in surface runoff and cause an increased accumulation of minerals and nutrients in the lake waters (Loehr, 1974; Qu'Appelle Basin Study, 1972; Rawson, 1951).

4.7.6 AGRICULTURAL CROPLAND DRAINAGE

Agricultural croplands which are poorly managed can cause substantial deterioration of water supplies. The first problems may arise with the clearing of the land. The removal of vegetation and disturbance of the

soil can cause severe erosion problems.

Cultivation of the soil may make the erosion situation worse if reasonable set backs from waterways and attention to slope contours are ignored.

One of the major concerns over effects of agriculture on surface waters has been the potential of fertilizer applied to the land to reach and affect waterways. In actual fact, fertilizers are rarely directly responsible for the deterioration of water supplies. While only a small percentage of fertilizer applied to crops is actually used by the crop, most of the remainder is converted to form insoluble products which are not mobile in most soils and very little ever reaches surface or ground waters. The little that may reach ground waters may be taken up by other vegetation, provided that cultivation does not extend right to the surface waters. The potential for problems due to poor erosion control is greater since the fertilizers are generally 'fixed' in topsoils, which are the first to be eroded, carrying the fertilizers N and P into surface waters (Loehr, 1974; Cooke & Williams, 1973; Parker, 1972).

The final area for potential problems due to agriculture is in the management of crops and crop residues. Nutrients may be leached from the plants themselves or from stubble left in fields, particularly after frost conditions or severe dehydration when the permeability of plant cells has been altered. These leached nutrients are unlikely to reach surface waters unless the fields are too close to waterways (Timmons, et.al., 1970).

4.7.7 LIVESTOCK WASTES

Contaminants from animal and livestock wastes can be a very large

nutrient source if there is not adequate waste control. In addition to direct pollution from animal wastes, livestock tramples shore and beach areas, increasing the erosion in those areas. Direct access by livestock to waterways should be restricted or prohibited and any concentrations of populations should be well away from streams, lakeshores and hills draining directly into surface waters. Contamination from stock effluent increases in wet or frosty weather so stock should not be sheltered in stream valleys (Loehr, 1974; Cooke & Williams, 1973; Qu'Appelle Basin Study, 1972).

4.7.8 RECREATION IMPACTS

Recreational impacts on surface waters are inevitable if an area is to be used for recreation but, with wise management, these impacts can be minimized. The impacts are generally site specific, occurring at facility sites, cottage developments, along trails and at beaches.

Trampling of soils, removal of vegetation and scuffing away of leaf litter increase the compaction of soils, reducing the infiltration rate and increasing the erosion potential. Very coarse soils and soils with a high moisture content are most easily damaged so trails and heavy use areas should be located on soils of medium texture, preferably with a high organic matter content if they are not so close to waterways that leaching could be a problem (Dotzenko, et.al., 1967; Manning, date unknown).

Sewage disposal for camp grounds and cottage areas should be carefully chosen and located to suit the site conditions. Seepage from septic tanks and outhouses can be a major contributor of nutrients to groundwater and interflow (Gorski & Rybak, 1974; Loehr, 1974; Qu'Appelle

Basin Study, 1972).

Holiday boats tend to stir up sediments which can stimulate internal recycling of nutrients. They are also ideal transport mechanisms for introducing algal species from one lake or section of a lake to another.

4.7.9 INTERNAL RECYCLING

Once nutrients and elements reach the waters of a lake, they are not simply used and then lost to the system. In earlier sections of this chapter, it has been pointed out that there are many complex cycles functioning within a lake system which serves partially to regenerate nutrients and minerals in the same or different forms for reuse by other organisms. Decomposing plankton and plants are important internal nutrient sources as is the organic waste excreted by the living organisms (Barica, 1974; Fast, et.al., 1973; Fish, 1972; Brown, 1972).

It has also become clear that some of the nutrients which were thought to be lost due to sedimentation are recycled. Virtually all of the nutrients and minerals which make up the chemistry of lake waters are sedimented out to some degree. A great deal of work has been done to discover the role of lake sediments in regenerating nutrients, particularly N and P compounds. It is not yet known conclusively whether or not sediments always act as a net sink for the nutrients but it is clear that at least a small percentage of them are recycled (Serruya & Berman, 1970; Delfino, et.al., 1969).

The mechanism that controls the sedimentation and release of P compounds is commonly believed to be a chemical reaction with iron. The precipitation of P occurs under oxic conditions with subsequent freeing occurring due to reduction of iron under anoxic conditions (Osborne &

Moss, 1977; Barica, 1974; Bortleson & Lee, 1974; Schindler & Lean, 1974).

Several mechanisms are thought to have an impact on the release of P and other constituents from sediments including diffusion, turbulent mixing, biological microorganism activity and geochemical processes (Bannerman, et.al., 1975; Barica, 1974; Brezonik, 1972; Carleton, 1972; Li, et.al., 1972; Schindler, et.al., 1972). The top centimeter or so of sediment and interstitial muds appear to be the main zone of recycling activity with little or no effect below 5 to 15 cm (Carleton, 1972; Kemp. 1971). The release of nutrients from sediments is probably most active in winter ice-covered conditions where an anoxic hypolimnion has developed (Osborne & Moss, 1977).

It is difficult to ascertain whether or not these reactions will take place at a sufficient rate to be a relevant nutrient source but it is wise to be aware that a potential for it does exist (Gachter, et.al., 1974; Brezonik, 1972; Carleton, 1972).

4.8 SUMMARY

The still waters of a lake provide excellent conditions for abundant primary production. While some production is beneficial and desirable, excessive amounts reduce the potential for use of lake water and affect the aesthetic qualities. Inputs of nutrients are a decisive factor in governing the rate of photosynthesis. Lake metabolism is influenced by all components of the drainage basin and any conditions in the basin which increase sediment, nutrient and/or mineral loads in runoff will affect the waters of the lake. It is, therefore, pertinent to attempt to establish source areas where excessive inputs may be occurring.

In most cases, the extent of pollution depends more on management practices than on the type of activity itself. Where this is the case, it may be possible to adjust land use practices to benefit the lake environment rather than instituting major changes in zoning or prohibition of land uses.

CHAPTER 5

ANALYSIS OF DATA AND CONCLUSIONS

In the preceeding chapters, I have outlined what the Sturgeon Lake drainage area is like and how lake systems in general respond to different stimuli. It is now possible to examine and interpret the data collected at Sturgeon Lake during the summer of 1978. It is my intention to examine the cause/effect relationships between water quality and land use in this basin. I will assess the current condition of the water and the impact which existing developments have had on the lake. It is then possible to project what the effect of future developments may be. This will be done by quantifying the present use pressure on the lake and comparing it to a theoretical resource use capacity.

5.1 LAKE CIRCULATION

Any satisfactory water quality study in which an attempt is made to identify nutrient sources must take into account the movement within those waters which serves to disperse sediments and affect the availability of nutrients. There are many ways in which this knowledge may be gained but most are very complex, expensive and not entirely satisfactory.

For this study, a number of methods were utilized to estimate the major water movement patterns. Wind and wave direction were noted at each sample site on every sampling day. The direction of boat drift from the anchor was also noted. On two occasions, confetti was scattered onto the water surface at several locations and subsequent directions of movement were observed. An examination of remotely sensed images of the lake was also used to indicate overall patterns

of water movement.

Sturgeon Lake is an open system with the major inflowing stream situated quite close to the lake outflow. A relatively direct flow-through pattern in the south east corner of the lake seems to be further intensified by the prevailing wind direction which is toward the outflow. Indeed, all of the tests conducted indicated that the general direction of drift was from west to east unless there was a relatively strong wind from another direction. Surface water movement close to shore is toward that shore. The water of the western arm does not appear to mix freely with the main basin water due to the constriction of land called the narrows. However, wave direction in the narrows was predominantly from the bay into the main basin so some mixing must occur.

It is thought that currents induced by wind action are the most active water movements in Sturgeon Lake. Temperature changes at spring overturn undoubtedly cause vertical displacement, at least in the main lake basin. As mentioned above, inflow induced circulation is very important in part of the lake.

The observations made of water movement all dealt with surface circulation. It is also important to know how bottom currents respond to the surface conditions not only because of their effect on the movement of nutrients but also because of their ability to disturb bottom sediments. The stirring of sediments allows the release of nutrients to the water which would otherwise be unavailable for use in primary productivity.

A method of calculating the critical depth (or mixing depth) of a wave was developed by Sverdrup, et.al.(1942). The data with which this

calculation may be made were not collected for Sturgeon Lake. However, calculations by Hickman (1979a & b) for Cooking Lake and Ministik Lake established critical depths of 5 m and 5.5 m respectively at wind speeds of 20 to 25 km h^{-1}. It is felt that this is also the approximate range of critical depth for the same wind speeds at Sturgeon Lake. Since the mean depth of Sturgeon Lake is 5.7 m and the lake experiences windy conditions frequently, it can be assumed that wave action is stirring bottom sediments over much of the basin for a large part of the open water season. The area along the western shore of the lake is protected from the prevailing winds and much smaller waves are experienced than on the eastern shore. It would follow, then, that there would generally be less disturbance of bottom sediments along the west shore than there is along the east shore.

Photo 4 is a remotely sensed image of Sturgeon Lake taken on June 6, 1977. It has been density sliced and color coded on a microdensitometer (see 'density slicing' in appendix 5). Although it does not clearly show water movement patterns, due to the influence of factors such as aquatic vegetation, it is possible to see some evidence of circulation patterns. The distinctive horizontal lines are the scan lines and should be ignored. Assuming that 1977 was similar to 1978, macrophyte growth was not very far advanced in early June. Therefore, the density variations in the image are largely the result of turbidity and phytoplankton differences. At the time of the passage of the satellite, winds in this area were out of the east at 17 km h^{-1}. It is for this reason that the west shores show up as being the more turbid areas. The waves are disturbing the bottom sediments all along these shores. An indication of a flow-through pattern from Goose Creek toward Sturgeon

PHOTO 4: DENSITY SLICED BAND 6 REMOTELY SENSED IMAGE OF STURGEON LAKE.

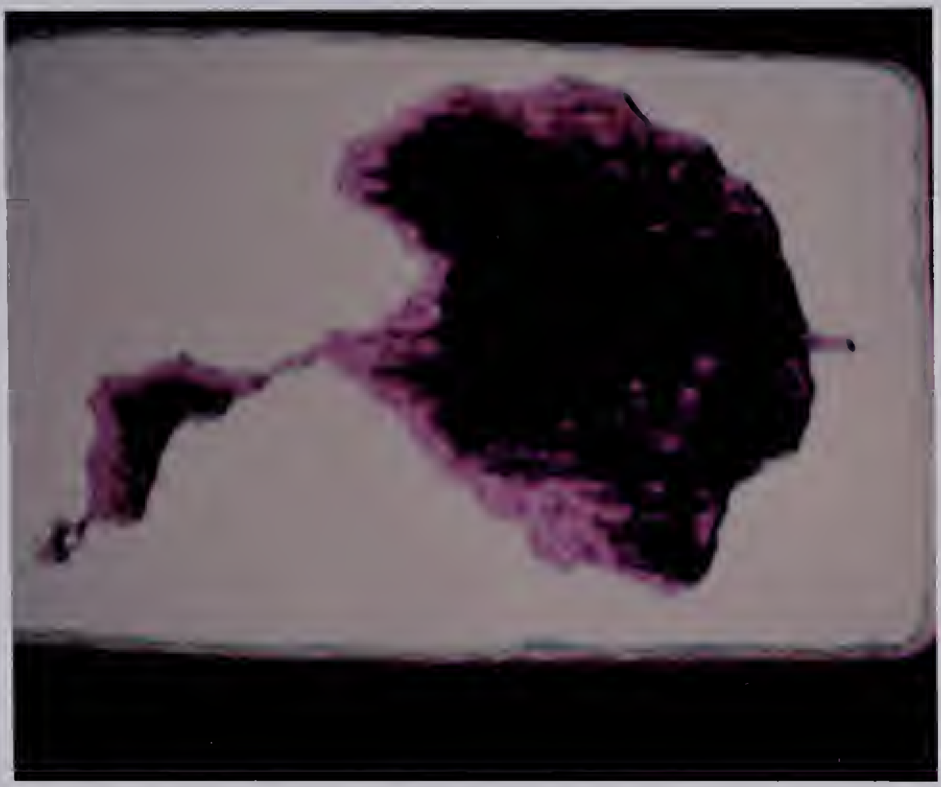
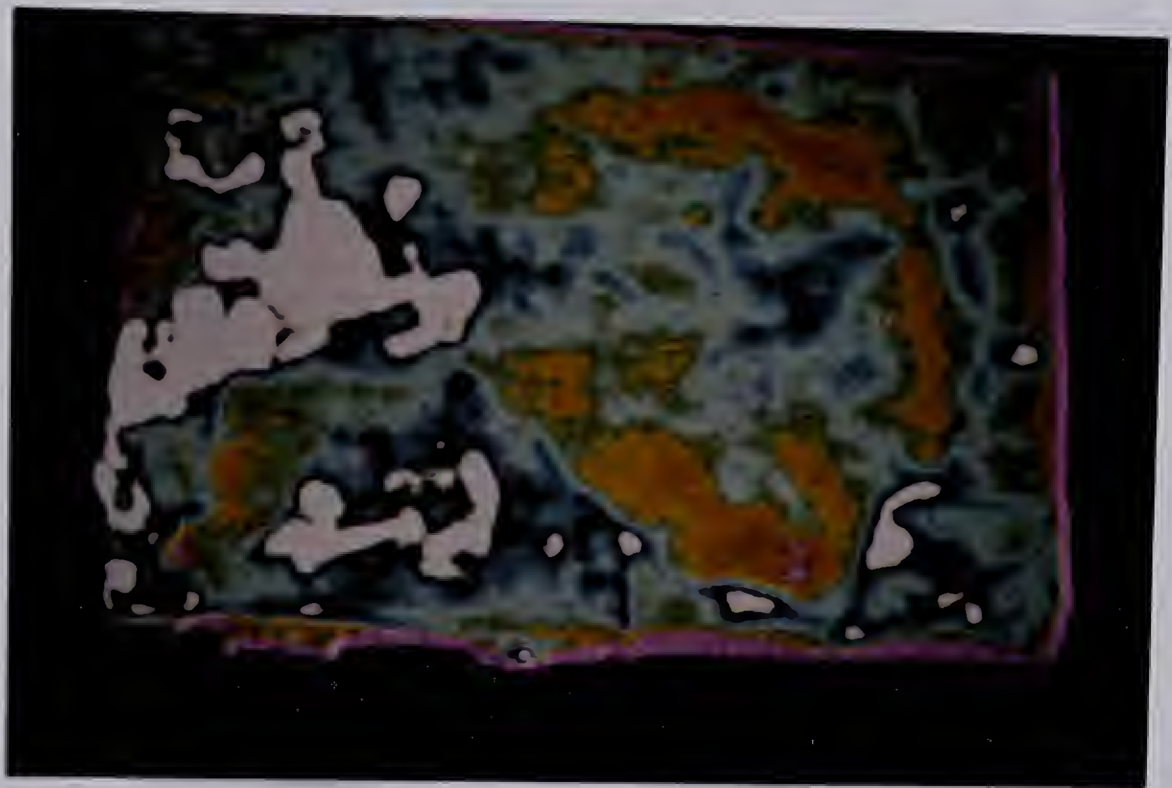


PHOTO 5: DENSITY SLICED BAND 4 REMOTELY SENSED IMAGE OF STURGEON LAKE.



Creek can also be seen.

My observations indicate that wind is the chief director of water currents in Sturgeon Lake and that the currents are highly variable because of that. On calm days, the general trend of water movement is toward the Sturgeon Creek outflow although the northwest and northeast corners of the lake tend to exhibit spiral currents.

5.2 WATER QUALITY

Water quality samples were collected from a number of different sites in and around Sturgeon Lake during the summer of 1978. This method of sampling made it possible to draw comparisons between the various sites and to get a good impression of the overall quality of water in Sturgeon Lake.

Water samples were collected from between five and eleven of eleven sampling sites on fourteen days between May 13 and September 16, 1978. One grab sample was taken from Grassy Lake, site L, on August 8 (see figure 2). The grab sample from Pelican Lake was not analyzed due to an unfortunate accident which caused the sample to be lost. However, it is felt that the conditions in Pelican Lake were very similar to those in Grassy Lake.

The dates on which samples were collected were: 1) May 13; 2) May 22; 3) May 28; 4) June 4; 5) June 11; 6) June 18; 7) June 25; 8) July 3; 9) July 10; 10) July 16; 11) July 25; 12) August 3; 13) August 11; 14) September 16. Henceforth the number of the sample date will represent that date when used in a table or graph.

The locations of the sample sites, designated A to L, are shown on figure 2. Sites A to G are located in the main basin of the lake,

sites H to J are in the western arm of the lake, site K is in Goose Creek about halfway between Goose Lake and Sturgeon Lake and site L in in Grassy Lake at the south end of the basin.

5.2.1 REMOTE SENSING OF WATER QUALITY

Remotely sensed images have been utilized for a number of water quality and lake circulation studies with reasonably good results (Cochrane & Hajic, 1978; Moore, 1978; Benton & Newnam, 1976; McNeil, et.al., 1976; Abiodin, 1975; Rogers, et.al., 1975; Goldman, et.al., 1974; International Joint Commission, 1974; Strong, 1972; Arvesen, et.al., 1971; Fraga, 1969; Fraga, 1967).

The use of remotely sensed imagery to correlate with ground sampling to establish turbidity patterns over the whole lake proved to be somewhat disappointing. Due to the fact that the signal received represents a mix of effects due to water color, suspended sediment and aquatic vegetation, it proved to be virtually impossible to separate and correlate all of the data.

Photo 5 has been included to show what the relative transparency of the water was on July 25, 1978. The photo is a color coded density sliced band 4 image. The dark area is the clearest water in the lake and the green areas are the least clear. The orange areas may be mid-range in clarity but it seems more likely that macrophyte growth is influencing the response in these locations. The problem with correlating data over the lake arose chiefly because of this vegetation influence. It would have been better to arrange the coincidence of ground truthing with the passage of the satellite for a day in the spring before aquatic vegetation had become such an important factor.

Nevertheless, it is interesting to note the area of the lake which exhibits the greatest clarity. This pattern may be compared with that of photo 4, a band 6 image of conditions on June 6, 1977. Apparently, the north central part of the basin is usually clearest and the surrounding main basin is slightly less clear. The areas closer to shore are apt to be more turbid, probably due to the stirring of bottom sediments into suspension by wave action.

5.2.2 SUMMARY OF RESULTS

A brief summary of the data results for the parameters tested is presented in sections 5.2.2.1 to 5.2.2.4. Comparisons between the results and discussion of the implications are included in section 5.2.3.

The mean summer value and the range of values for fourteen of the parameters tested are listed in table 9. The locations for which results are listed are: site E, Goose Creek, the main inflow to the lake; site D, Sturgeon Creek, the outflow from the lake; the average of all the lake sites sampled; the average for the main basin of the lake; and the average for the western arm of the lake.

Appendix 4 contains tables of almost all of the water quality data obtained during the summer of 1978. Only those results which were thought to be dubious due to conversions which probably occurred during transit (eg: ammonia) have been omitted.

5.2.2.1 PHYSICAL PARAMETERS

Water temperatures in Sturgeon Lake are generally good but they did reach potentially critical levels in mid-summer. The highest recorded temperature was 24.6°C at site H. Temperatures of 20°C are approaching the lethal limit for whitefish (Bishop, 1971a, pg.10). Since there

TABLE 9 SUMMARY OF WATER QUALITY DATA

PARAMETER	Chl. a ($mg\ m^{-3}$)	total PO_4 ($mg\ l^{-1}$)	total Kjd. N ($mg\ l^{-1}$)	Si ($mg\ l^{-1}$)	Fe ($mg\ l^{-1}$)	temp. ($^{\circ}C$)	pH (units)
Site E: mean	8.3	0.75	1.24	1.44	0.73	16.5	7.34
range	0.7-30.2	0.52-0.89	0.11-2.08	0.93-2.20	0.22-1.19	9.6-20.7	6.50-8.34
Site D: mean	20.3	0.51	1.28	0.74	0.21	16.6	7.88
range	5.2-76.1	0.31-0.99	0.71-3.30	0.32-3.00	0.04-0.46	9.5-20.8	6.60-10+
Lake: mean	21.3	0.57	1.48	1.22	0.25	17.3	7.98
range	0.7-150.5	0.28-1.14	0.11-6.08	0-5.10	0.03-1.19	9.5-24.6	6.49-10+
Main Basin: mean	19.5	0.53	1.18	1.13	0.24	16.9	7.76
range	0.7-124.1	0.28-0.99	0.11-3.30	0.32-3.90	0.03-1.19	9.5-23.8	6.49-10+
West Arm: mean	26.5	0.65	2.18	1.43	0.27	18.3	8.48
range	1.1-150.5	0.35-1.14	0.90-6.08	0-5.10	0.06-0.78	10.9-24.6	6.59-10.00

continued next page -

TABLE 9 SUMMARY OF WATER QUALITY DATA (CONT'D)

PARAMETER	turbidity (JTU)	D.O. (ppm)	color (TCU)	alkalinity as $CaCO_3$ (mg l^{-1})	hardness as $CaCO_3$ (mg l^{-1})	conductance (micromhos)	TDS (mg l^{-1})
Site E: mean	5.91	6.85	223.8	55.6	74.3	152.7	149.3
range	1.5-20.0	5.47-9.83	80-310	48.8-69.6	60-92	130-190	121.6-194.0
Site D: mean	4.60	9.00	97.6	53.2	76.6	163.2	133.3
range	0.4-19.0	6.55-10.40	72-187	48.1-63.9	60-164	145-190	91.9-176.3
Lake: mean	5.86	8.91	113.6	54.4	72.5	162.2	139.2
range	0.4-59.0	5.47-15.48	65-310	43.0-75.1	60-164	130-250	76.7-295.4
Main Basin: mean	3.87	8.82	103.8	54.1	71.6	159.6	131.8
range	0.4-25.0	5.47-13.56	65-310	47.4-69.6	60-164	130-190	76.7-194.0
West Arm: mean	10.51	9.10	136.3	55.0	74.8	168.0	156.4
range	1.3-59.0	7.01-15.48	96-232	43.0-69.0	60-136	135-250	95.7-295.4

source: Author

was no fish kill resulting from the high temperatures, the temperature in deeper water must have been cooler. The western arm of the lake warms up earlier and to a higher level than the main body of the lake. It also cools off earlier in the fall. Rapid heating of water in spring is characteristic of the shallow, eutrophic lakes commonly found in Alberta (Hickman, 1979a, 1979b, 1978). This is chiefly due to the shallowness of the water. The highest mean temperature was for site E.

Mean pH values were all within the recommended limits as was the lower end of the range of values. Extreme alkaline values of over 9.0 were quite frequent, usually occurring in the west arm during late summer. This may be due to the effects of biotic respiration which were higher in the west arm than in any other part of the lake. pH values increased through-out the lake as phytoplankton photosynthesis (as indicated by chlorophyll a concentrations) increased. The most acidic values (6.42 and 6.61) were found at sites L and K respectively. Water from these sites drains to site E, the lake site with the lowest mean pH value (7.34). It is well known that marshy or muskeg wetlands produce acidic waters.

The Goose Creek site also exhibited the greatest degree of color in the lake with the upstream sites, K and L, being even more highly colored. The large amounts of organic material present in swamps and marshes account for the coloring. The west arm, which is also fed partially from wetland areas and has a muck bottom high in organic content, is also highly colored. The three sites along the west shore of the main basin (A, E & G) have the lowest color values.

The west arm of the lake is considerably more turbid than the rest of the lake with site H at the Cozy Cove marina having by far the highest mean value. This is because of the finely textured bottom sediments being stirred up by the motor boats. The second highest mean turbidity value is for site K. This site is a section of Goose Creek which has open access for a herd of cattle. The banks are severely broken down (see photo 6), causing significant erosion. The sites with the lowest mean turbidity were A and G. Both of these sites are on the lee shore to the prevailing winds and have sand bottom sediments. This may indicate that there is a cause and effect relationship here, with wind induced currents stirring up bottom sediments in some locations (eg. B & E). Site E water is also relatively turbid due to upstream effects.

Secchi disc readings were compared to chlorophyll _a_ and turbidity data. It was found that they related quite closely to the turbidity results with the clearest water at sites A & G. The lowest mean readings were taken at sites H, I & J. Correlations with chlorophyll _a_ did not show as good a correspondence. Secchi readings taken in the middle of the lake on two occassions averaged out at 1.6 m. The mean value for the regular sampling sites was .81 m. This agrees with the interpretation of water clarity patterns based upon the remotely sensed images.

Dissolved oxygen levels are generally very good and are well above critical levels during the day in summer. The lowest values of 6.7 and 4.29 ppm were obtained for sites K & L, where decomposition is probably more active for most of the year. Winter measurements of D.O. under ice cover would probably be closer to critical levels although winter fish kills are not a common occurance at present. It is

PHOTO 6: SAMPLE SITE K ON GOOSE CREEK WHERE CATTLE HAVE TRAMPLED THE SHORE.

PHOTO 7: SHORE SLUMPING ON EDGE OF FARMLAND AT SAMPLE SITE J.

also important to note that all of these samples were taken during mid-day and D.O. would decrease during the night, possibly even nearing critical levels due to the large amount of aquatic vegetation respiration. Diurnal changes of 4 to 6 mg l^{-1} are not unusual (Wetzel, 1975).

5.2.2.2 MAJOR IONS

The measured values for chloride, sulfate, sodium and potassium are presented in the tables in appendix 4. These ions are all well within the recommended limits.

Specific conductance measurements were highest in the western arm with site I having the highest mean value. This indicates a higher mineral content in these waters. This is also indicated by high TDS values for that area. These parameter results may indicate that erosion from the surrounding land is affecting the waters of the lake. Photo 7 showing erosion of the lake shore in a farming area is one source location. This could also be part of the reason for the high turbidity values in the western arm.

Hardness measured as calcium carbonate indicates that the lake waters are usually in the moderately soft category (see table 8) with the range occasionally extending into the limits of hard water. Alkalinity is well within the guideline limits in both directions.

5.2.2.3 CHLOROPHYLL a

Only the interrelationships between water chemistry and phytoplankton have been considered in this study (see section 5.2.3.3). However, other components of the ecosystem such as phytobenthos, zooplankton and fish will also be affected by the water quality.

August 11 was the date on which the mean value of all samples was

highest and June 4 had the lowest value. The highest recorded concentration was at site J on August 3 and the lowest was at site E on May 28. Site E also had the lowest mean site value. Site H had the highest mean site value in the lake.

5.2.2.4 NUTRIENTS

The analysis of water samples for P content was done on unfiltered water. Therefore, total P as measured includes the particulate fractions of P (i.e. that which has already been incorporated in phytoplankton and zooplankton). Of the three fractions of P which were measured, only ortho P has been included in the appendix 4 tables. The patterns of ortho P were very similar to those of total P so only the latter will be discussed. It has been pointed out by researchers such as Oglesby and Schaffner that the use of total P in nutrient studies may be misleading (Hickman, in press, 1979a, 1979b, 1978; Mitchell, 1979a). The portions of P input which are adsorbed onto soil particles are thought to be unavailable for algae utilization so using total P values tends to overestimate the usable P. However, most studies to date have used total P and, therefore, it is safe to use it in this study for comparative purposes.

Site E was the lake location with the highest mean P value, with even higher mean values recorded at sites K and L. The highest lake value measured was 1.14 mg l^{-1} at site J on August 3. The highest measured spring concentration was 1.11 mg l^{-1} at site I. The lowest mean value for a sample site was at G. This was also the site where the lowest recorded value of 0.28 mg l^{-1} was found. The highest mean values for sampling days were May 22 and August 11 and the lowest was on

June 4 but the difference between high and low values was very small. The mean supply of P in the lake appeared to be quite consistent through-out the summer.

The fractions of N which were measured have also been discarded in favor of using only total Kjeldahl N. This is because it appeared that the relative amounts of each fraction had changed due to the unavoidable delay between the time samples were taken and when they arrived at the lab. These reactions would not alter the total amount of N.

Site H has the highest mean value for total N in the lake and site F had the lowest mean. The highest recorded value of 6.08 mg l^{-1} was on August 3 at site J and the lowest, 0.11 mg l^{-1}, was recorded September 16 at site E. An even higher value of 3.73 mg l^{-1} was found at site L, Grassy Lake. The mean value for site K, 1.5 mg l^{-1} was midway between the values for the main body of the lake and those for the western arm. The west arm exhibited a significantly higher mean summer value than that of the main body of the lake. The highest spring value 2.92 mg l^{-1}, was recorded at site I and high fall values were found at sites D, J & H. The highest mean sampling day value was on August 3 (2.35 mg l^{-1}) and the lowest was on June 4 (0.79 mg l^{-1}).

The highest spring measurement of silica was found at site E. Late summer values increased first at sites H and J, but by fall values had increased over the whole lake. It would seem from the magnitude of the fall increase that there were probably also high spring values before sampling began. The highest mean value for a sample day was on September 16 and the lowest mean values were obtained on June 4 and

July 16. The highest mean value for a site was at H and the highest recorded value of 3.0 mg l^{-1} was found September 16 at site J. The lowest value recorded was 0 on May 22 at site I. This is below 0.5 mg l^{-1} which is required for diatom growth. Between May 22 and July 25, values below this minimum were found at sites A, B, C, D, G, I and J. However, mean daily and site values were always above the minimum requirement.

The highest values for iron were found in the spring and the lowest in late summer. The mean values over the lake were all within suggested limits. Values occasionally exceeded the recommended limits at sites E, I and K but, for this parameter, exceeding the guidelines is not critical.

5.2.3 DISCUSSION OF RESULTS

5.2.3.1 COMPARISON WITH DATA COLLECTED FOR PAST STUDIES

There have been a few water quality studies conducted on Sturgeon Lake water prior to this study. Although none of them were as intensive as this one, it has been possible to draw a few comparisons.

The studies conducted by Bishop (1971a and 1977a) tested for physical and chemical water quality, taking samples from 5 locations. He found that there was no thermocline developed in the lake until winter came, and then the inverse thermocline which developed had a very small top to bottom temperature difference. D.O. levels reached a maximum of 8.5 ppm in August and dropped to 4 ppm in October. Hypolimnetic oxygen was only 0.5 ppm in April. In 1976, his survey of bottom materials turned up some results which implied that reducing conditions were present in August at the sediment surface in the deep water zone. This

indicates that a summer thermocline with an anoxic hypolimnion may develop in some years at Sturgeon Lake. Plankton sampling for these studies showed blue green algae to be the most prominant form of phytoplankton, with a bloom of Anabaena at the end of June followed by a bloom of Aphanizomenon in August and September, 1969. One diatom, Stephanodiscus, was found to be fairly common through-out the year and one green algae, Volvox, was present only in early summer. June to October was the most productive season and August was the most productive month.

Gladish's study in the summer of 1975 involved sampling of water on three dates at the five locations which Bishop used. His analysis dealt only with water chemistry results.

In table 10 the available mean data for six parameters gathered for four different studies are compared with the closest sample date and location data for 1978. Assuming that sampling and analysis methods produced like results, it is possible to see if there have been any significant changes in the water quality of Sturgeon Lake during the ten years from 1969-1978.

The only significant difference in total P concentrations is in column 2, comparing the mean for the lake on August 10, 1975 and August 11, 1978. The difference here would seem to indicate that there has been a large addition of phosphates since 1975. However, since the 1976 data show no such increase, it is more likely due to some other cause. Gladish does not state in his paper whether he sampled for total P or for a fraction. This may also explain the large difference. Since the averages in both cases are for the whole lake and all five of his

TABLE 10 DATA FOR SELECTED PARAMETERS OVER TIME

Parameter	Date			
	July 4, 1969/July 3, 1978[1]	August 20, 1975/August 11, 1978[2]	July 16, 1976/July 16, 1978[3]	July 23, 1976/July 25, 1978[4]
total PO_4 ($mg\ l^{-1}$)	0.48/0.49	0.05/0.70	0.5/0.49*	0.36/0.49
total Kjld. N ($mg\ l^{-1}$)	-	-	-	1.23/1.45
silica ($mg\ l^{-1}$)	0.05/0.76	-	1.7/0.41*	-
iron ($mg\ l^{-1}$)	0.45/0.19	0.27/0.13	0.23/0.11	0.43/0.16
chlorophyll a ($mg\ m^{-3}$)	-	25.6/59.6	-	-
secchi (m)	-	0.84/0.55	0.9/1.0	-

* data for July 24, 1978
1 Bishop (1971a) compared to 1978 lake mean
2 Gladish (1976) compared to 1978 lake mean
3 Bishop (1977a) compared to site A 1978
4 Peace River Regional Planning Commission (unpublished data) compared to 1978 main basin mean

sample locations had similar results, as did all ten of my sites, it is unlikely that the difference lay in an unusual input.

The only total Kjeldahl N comparison shows no significant change between 1976 and 1978.

The silica data have major differences over time. Both previous samples were taken by Bishop (1977a and 1971a) at approximately the same time of year. The 1978 data lie midway between Bishop's data. Since silica is largely recycled within a lake system it is unlikely that the differences are due to varying inputs. Therefore, barring errors in analysis, the differences may be due to a shifting diatom bloom period in the different years.

Iron concentrations are consistently lower in 1978 than in any of the previous years. There may have been greater precipitation of Fe ions in 1978 but this process would probably also lower the available P. One would have to test the bottom sediments to determine if this was the case. Alternatively, it could once again be due to the analysis procedures. In this case, I question the 1978 data since the other samples are more in line with one another.

The only comparison for chlorophyll a concentrations indicates over a 100% increase in standing crop since 1975. While there may indeed have been a substantial increase in standing crop over time, the difference may also be due to two other factors. The first is that the 1978 sampling procedure included relatively more sites in the west arm than the 1975 procedure did and this may have skewed the average slightly. The other factor is that the 1978 sampling date was earlier in the month and was associated with an algal bloom. The later date in 1975

may have been into the start of the algal decline period.

Secchi disc readings in 1975 and 1976 are similar to those of 1978.

In summary, there does not appear to have been a consistent trend in any of the noticable differences in these water quality parameters in Sturgeon Lake during the ten years from 1969-1978.

5.2.3.2 COMPARISON OF SAMPLING SITES

It seems that site E consistently exhibited the most extreme mean values for every parameter measured except total N. It also supported the lowest mean standing crop. The upstream wetlands apparently supply the lake with many nutrients and sediments. Perhaps the high color and turbidity keep the light penetration low enough that algae do no grow well there. This, then, would explain why the nutrients are not readily utilized in primary productivity.

The data for the west arm of the lake are also consistently extreme for most of the water quality parameters measured. The shallow, nutrient rich waters support high chlorophyll a concentrations but are not in a range that would merit calling the waters polluted.

The only other site which showed significant differences was D, the outflow from the lake. The water here is of a relatively high quality compared to most of the other sites. Apparently many of the nutrients and sediments which are entering the lake are staying in the lake.

As far as the other sampling sites are concerned, it was found that there were few really significant variations between the sites. As has been previously mentioned, there is so much natural variation in the quality of surface waters that human induced variations from non-point sources must be quite large before they show up against the background

noise. However, while most of the absolute differences in concentrations of the parameters are not particularly great, their relative values were ranked to examine the site differences.

The Williamson Park site, F, exhibited relatively low nutrient and standing crop values. The cottage sites, G and C, had intermediate to low levels of nutrients and comparatively high standing crops. The sites representing agricultural use and the marina had relatively poor water quality, but, as both these sites are located in the west arm, the actual effect of the land uses on the water were blanketed by the obviously poor natural conditions. Sites A and B, representing the woodland area drainage north of the lake both had water quality which was mid-range for the lake.

While there probably has been some advancing of eutrophication over a long time period due to land clearing for agriculture, roads, construction of buildings, the introduction of cattle, and so on, it appears that relative to the natural quality of water in Sturgeon Lake there have been few significant anthropogenic effects. The most significant variations between sampling sites are due to natural causes rather than man-induced causes. However, care must be taken not to aggravate the natural ecosystem, which already is rich in nutrient sources, so that even more nutrients become available.

5.2.3.3 COMPARISON OF CHLOROPHYLL <u>a</u> AND NUTRIENTS

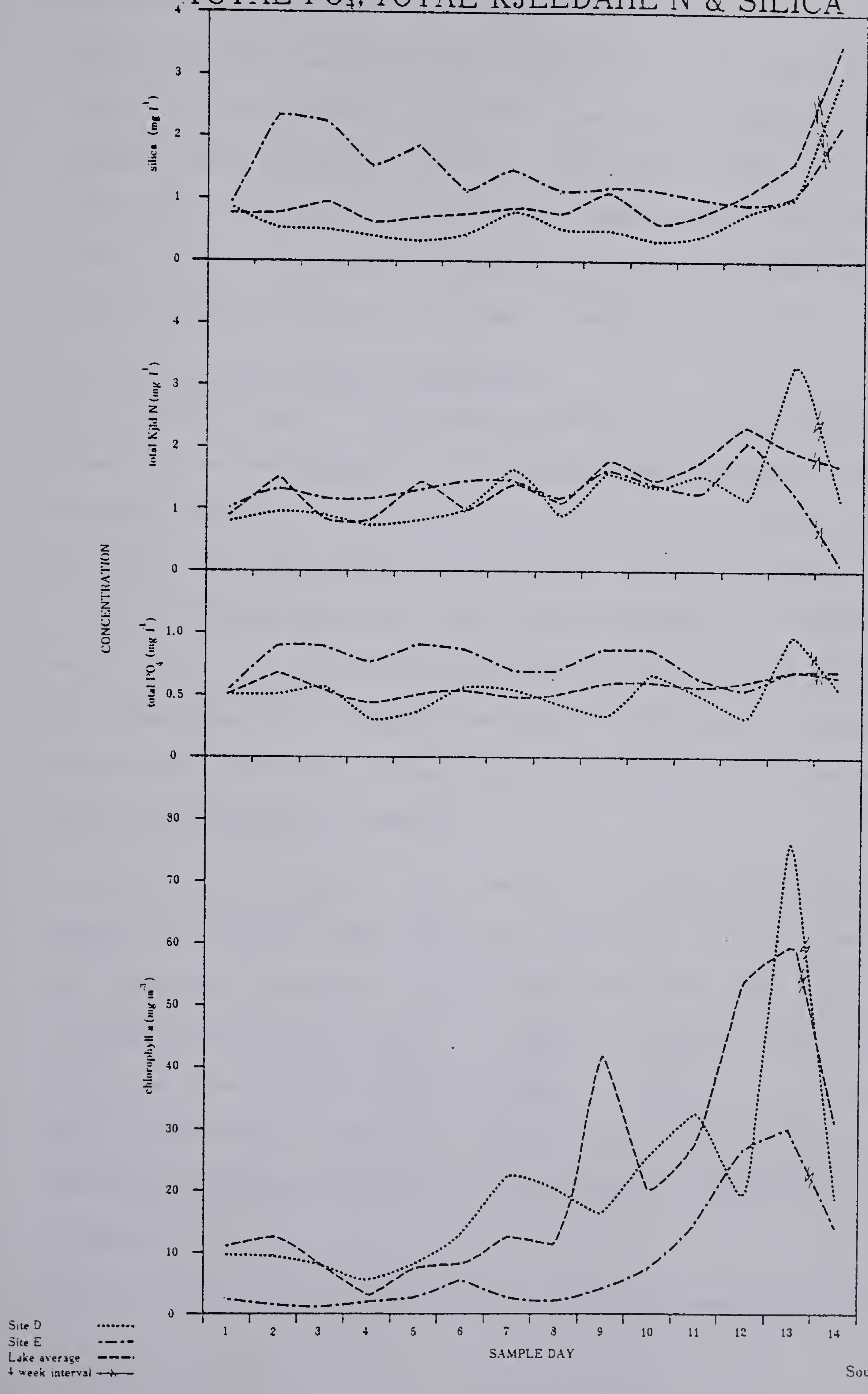
Much more is involved in the availability of nutrients than their total soluble concentrations in water and there is rarely a consistent pattern in phytoplankton responses to nutrient concentrations (Elder, et.al., 1979). The availability of various nutrients is complicated by

factors such as the relative amounts of the nutrients, the oxygen levels in the water, light levels and water movement. Together, these will control the growth and seasonal succession of phytoplankton.

Figure 25 is a graph in which chlorophyll a levels are compared with those of three nutrients. It show the results for site E, site D and the mean lake values over the sampling season for chlorophyll a, total PO_4, total Kjeldahl N and Si. According to analysis of these data, the spring bloom of algae in the lake was relatively small. On July 10, a larger bloom occurred but it lasted for only a week and was then followed by a late summer bloom which had declined by the middle of September. The method of sampling (i.e. a discrete sample from only one depth) could have biased these data but, since the lake waters were unstratified and generally well mixed, this should not have been a major problem.

With the exception of Si, the nutrients appear to parallel the chlorophyll a patterns quite closely. This was the expected result since the nutrient analyses were done on unfiltered water samples. Total Kjeldahl N is a measure of organic N and a large percentage of total PO_4 is organic. The portions of these nutrients which were already in algae in the sample were also measured in the nutrient analyses (Wetzel, 1975). Si, on the other hand, decreases in measured concentration as it is utilized by diatoms and increases when the skeletons degrade in the fall. The results on the graph indicate that diatoms still form a significant portion of the algae population in Sturgeon Lake. There are, however, factors other than silica concentrations which affect diatom populations so these data do not lead to

FIGURE 25 RELATIONSHIP BETWEEN CHLOROPHYLL *a*, TOTAL PO_4, TOTAL KJELDAHL N & SILICA



Source: Author

any conclusive results about the population.

Hickman (in press) has pointed out that winter concentrations of nutrients are very important to standing crop levels. Nutrient levels generally reach a maximum in Alberta lakes under ice cover just prior to spring thaw. Unfortunately, my sampling season did not begin until after nutrient levels began to decrease so I missed the best data from which to draw correlations with summer standing crops.

5.2.3.4 LIMITING NUTRIENT CALCULATIONS

One of the main aims in limnological studies is to find out which nutrient in the lake appears to be limiting further productivity and then ascertain whether or not controlling inputs of that nutrient to the system would effectively reduce productivity. Minimum P concentrations of 0.025 mg l^{-1} are required for algal growth (Qu'Appelle Basin Study Board, 1972). Even the minimum measured P level of 0.28 mg l^{-1} is 90% higher than this, so there is enough P in the lake to initiate productivity. This was obvious anyway by the presence of a large and healthy phytoplanktonic community.

P is the nutrient which is often limiting to primary productivity. However, the Canadian lakes where the concept of P limitation has been most thoroughly tested are in Ontario where the mean total P value for a number of lakes is 8.7 mg m^{-3}. In Alberta, the mean total P levels are in the order of 515.3 mg m^{-3} (Hickman, in press, pg. 4). Sturgeon Lake, in the summer of 1978, had a mean total P level of 570.0 mg m^{-3}. Obviously, conditions in Alberta are considerably different from those in Ontario.

An N:P ratio of 7.2:1 is required for planktonic algae growth (Hickman,

in press, pg. 3). As can be seen in table 11, lake nitrogen was theoretically limiting at all sites and on every sample day in 1978 at Sturgeon Lake. This is the case for most prairie lakes in Alberta (Hickman, in press). These conditions favor blooms of blue-green algae which are capable of fixing atmospheric nitrogen, thereby utilizing P even when N is seemingly limiting. Since it is virtually impossible to control N inputs to the lake, the only way to reduce productivity through nutrient control is to limit P inputs. If P is close enough to critical levels, it may be possible to effectively control inputs. However, with a mean N:P ratio over the whole of Sturgeon Lake being 2.6:1, it would be necessary to decrease available total P in the lake by at least 2.8 times before P would become limiting. Since P in this lake is primarily from natural sources, it appears that it would be virtually impossible to create a situation in Sturgeon Lake where either N or P could be effectively limiting to algal growth.

5.2.3.5 TROPHIC STATUS

Water classification systems are often organized to categorize water on the basis of average P concentrations. Lakes with more than about 30 mg P m^{-3} are generally considered to be eutrophic (State Lakes Preservation Committee, 1971; Bhagat, et.al., 1970). Therefore, Sturgeon Lake, (570 mg P m^{-3}) along with many other Alberta lakes, would be called eutrophic according to these standards.

Vollenweider (and Dillon, 1974; Dillon, 1974) has developed a method of estimating lake trophic status which is somewhat more refined than the above method. By correlating nutrient loading (usually total P) with mean depth and hydraulic residence time, it is possible to

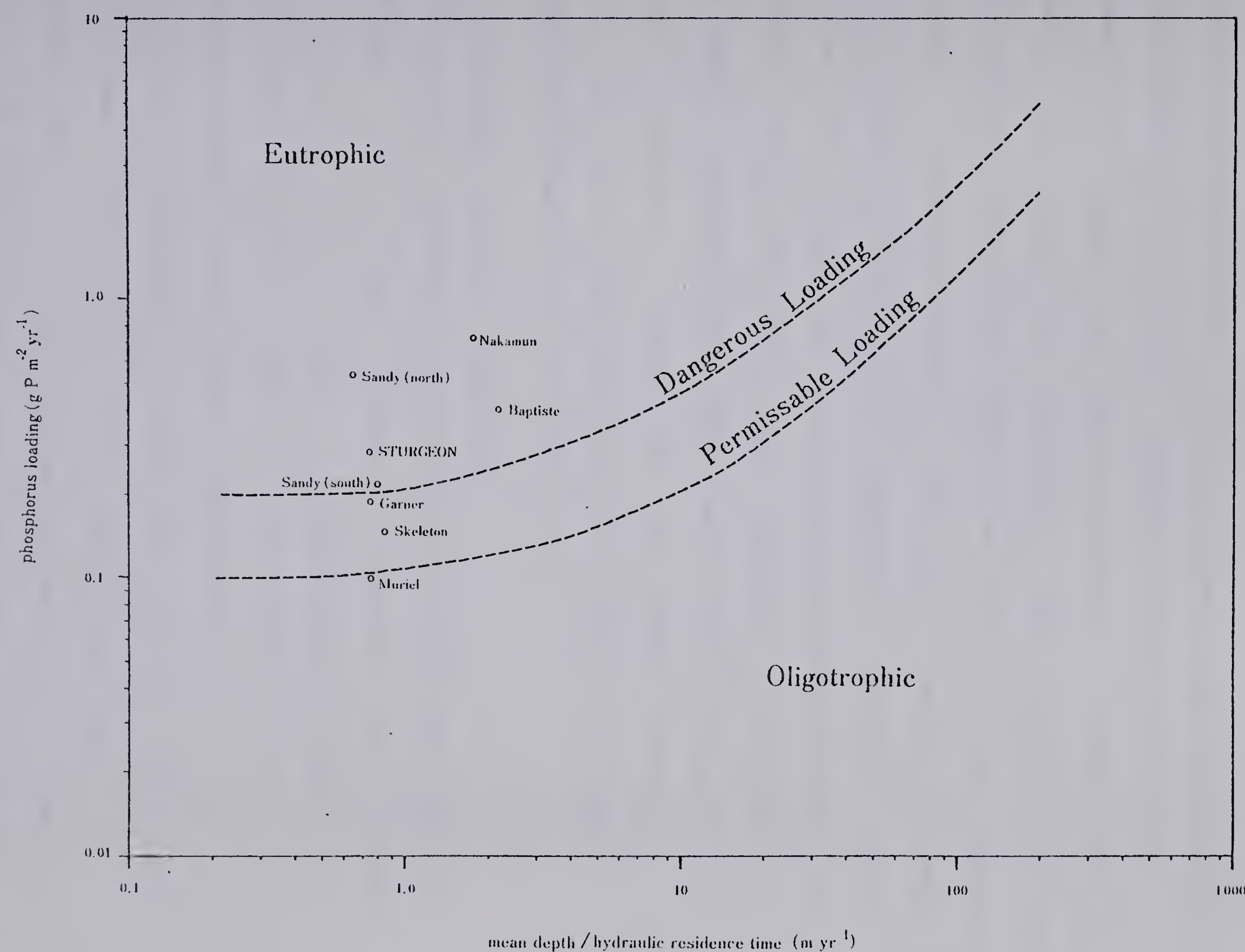
TABLE 11 N:P RATIOS FOR STURGEON LAKE, 1978
(mg l^{-1} N to 1 mg l^{-1} P)

site	mean ratio	sample day	mean ratio
A	2.6	1	1.7
B	2.0	2	2.2
C	2.8	3	1.7
D	2.5	4	2.0
E	1.7	5	2.7
F	1.5	6	1.8
G	2.8	7	3.0
H	3.6	8	2.3
I	2.7	9	2.9
J	4.0	10	2.3
		11	2.9
		12	4.1
K	1.1	13	2.8
L	3.0	14	2.6

lake average	2.6
main basin average	2.3
western arm average	3.4

estimate the amount of the nutrient load which will stay in the lake. The basis of this idea is that a high flushing rate will moderate the effects of high nutrient inputs. Nutrients which remain in the lake will increase the productivity of the lake until the saturation point is reached, thereby causing the lake to progress in the eutrophication process. When the data for Sturgeon Lake were plotted on the graph (figure 26), it was found that the lake fell in the eutrophic category. Six other lakes in Alberta which were studied by Mitchell (1979a & 1979b)

FIGURE 26 VOLLENWEIDER'S TROPHIC STATUS MODIFIED DIAGRAM



Source: Mitchell, 1979a & 1979b; Author

have also been plotted on the graph for purposes of comparison.

In order to ascertain how productive Sturgeon Lake is in relation to several other Alberta lakes, a table was drawn up comparing chlorophyll a concentrations (see table 12). Whenever possible, the data from mid-May to mid-September were obtained since that is the time frame for which data are available for Sturgeon Lake. Where annual data are used the figures are considerably lower than they would be if only summer data were used. It is also important to note that the timing of the sample season and the year of sampling are important (eg. Hastings). Out of 28 lakes listed, Sturgeon Lake is thirteenth, although this position would vary slightly from year to year. Apparently, on the basis of this sample of Alberta lakes, Sturgeon Lake is moderately productive in terms of chlorophyll a. Sturgeon Lake also supports a commercial fishery and an active sport fishery, indicating that productivity is good in terms of the higher species in the food chain.

5.3 DEVELOPMENT CAPACITY CALCULATIONS

There is general agreement among planners and managers that there are development capacity limits for each lake but there is some controversy over how they are best calculated. The capacity which is most often dealt with is the physical capacity or the environmental and ecological constraints which limit the amount of human activity that a given area can effectively accommodate. Two other limits which are also utilized are the human activity capacity and the physiological capacity (Jaakson, et.al., 1976). The former establishes limits in terms of density of people while maintaining activity safety and efficiency. The latter is an aesthetic parameter based on the acceptance of the density of use by the users. Ultimately, all development capacity

TABLE 12 CHLOROPHYLL a PRODUCTIVITY IN SEVERAL ALBERTA LAKES

Lake	Sample Season	Mean Chl. a Conc. ($mg\ m^{-3}$)
Miquelon[1]	May 25, 1973 - Sept. 4, 1973	2.5
Miquelon[1]	May 12, 1974 - Aug. 6, 1974	3.1
Muriel[2]	March, 1975 - Sept., 1978*	3.3
Sylvan[1]	May 30, 1973 - Sept. 11, 1973	3.89
Pigeon[1]	May 17, 1974 - Aug. 8, 1974	5.98
Gull[1]	June 1, 1973 - Sept. 10, 1973	6.98
Sylvan[1]	May 15, 1974 - Aug. 14, 1974	7.01
Buffalo[1]	May 16, 1974 - Aug. 15, 1974	7.77
Garner[2]	Oct. 18, 1977 - Oct. 23, 1978*	7.8
Buffalo[1]	May 31, 1973 - Sept. 19, 1973	7.83
Gull[1]	May 15, 1974 - Aug. 13, 1974	9.79
Pigeon[1]	June 7, 1973 - Sept. 18, 1973	10.38
STURGEON[3]	May 13, 1978 - Sept. 16, 1978	21.3
Moose[1]	June 14, 1973 - Sept. 27, 1973	21.63
Sandy (south basin)[4]	October, 1977 - October, 1979*	21.8
Skeleton[2]	October 20, 1977 - Oct. 23, 1978*	23.3
Hastings[5]	October, 1975 - Sept., 1976*	29.4
Nakamun[4]	October, 1977 - October, 1979*	34.5
Moose[1]	May 22, 1974 - Aug. 21, 1974	39.35
Hastings[1]	May 27, 1976 - July 27, 1976	43.03
Sandy (north basin)[4]	October, 1977 - October, 1979*	43.9
Hastings[1]	May 28, 1975 - Sept. 15, 1975	55.14
Joseph[1]	May 20, 1975 - Sept. 29, 1975	55.87
Oliver[1]	May 14, 1974 - Sept. 24, 1974	56.15
Beaverhill[1]	June 2, 1974 - Sept. 17, 1974	55.87
Ministik[1]	May 22, 1975 - Sept. 8, 1975	66.48
Cooking[1]	June 8, 1973 - Oct. 12, 1973	73.56
Cooking[1]	May 13, 1974 - Aug. 7, 1974	81.18

* annual data

sources:

1 Hickman, unpublished data

2 Mitchell, 1979a

3 author

4 Mitchell, 1979b

5 Hickman and Jenkerson, 1978

calculations are based on value judgements and the demand by users. Even ecological indices which are scientific in their measurement of environmental quality become value judgements when the acceptable level of change is established.

There are many ways in which lake managers attempt to estimate how much use can be made of a lake and the land around it without affecting the lake in a detrimental manner. The key to all of the methods is to be able to establish with reasonable accuracy what the bounds of resiliency are for each lake. That is, the capability of the lake to assimilate inputs and adapt to disturbances without changing the essential character of the ecosystem. It is desirable to estimate the levels and types of uses to which it may be put without accelerating the natural eutrophication process. This is done by first establishing the trophic status of the lake and the resilience of the lake to various uses, and then to assess the impact to the system which is generated by the present and proposed uses. The objective of the management plan is to ensure that the resource will be efficiently utilized without having the combined effect of the uses surpass the threshold established.

Five methods of calculating the development capacity of Sturgeon Lake follow. The first is a physiological capacity and an estimation of present use. The latter four are assessments of physical capacity with the third method including a judgement of human activity capacity. All five calculations were done for Sturgeon Lake by other researchers and are simply presented and commented upon. In some cases, the findings have been adjusted when data collected were different from those used in the original calculation. Section 5.3.6 is a compilation of all of

the findings regarding development capacity and an assessment of the present use level of Sturgeon Lake.

5.3.1 USER SURVEYS

A survey of cottage users at Sturgeon Lake was made by Gladish (1976). Although he got only 12 returns, the estimate he was able to make of use seems to be a reasonable one. It is therefore assumed that there is an average of 300 user days per cottage per year.

Wight and Mack (1975) conducted a user survey of Sturgeon Lake and found that recreational uses were family oriented with the most popular activity being fishing. Other popular activities included camping, picnicing and beach activities. They estimated current use to be in the order of 350,000 to 400,000 user days per year. This was later re-estimated downward to 70,000 - 120,000 user days per year (Peace River Regional Planning Commission, 1978). The reduction in user days is mainly attributable to the change from counting the permanent residents in the recreational use estimate. The estimates of resort and provincial park use were also reduced somewhat. The reduced estimates appear to be legitimate for recreational use. For this study, the upper limit of 120,000 user days per year has been used to include the increase in use which has probably occurred with the opening of Young's Point Provincial Park. It is also important to note that, while it is legitimate to use a lower figure for permanent residents when estimating recreational use, calculations based on environmental factors should include all use made of the area.

The Wight and Mack (1975) study found that recreational users of Sturgeon Lake felt that the area was very close to the desirable level

of development. This is the usual response of recreational users who are not likely to favor additional competition for space.

5.3.2 SHORELAND CAPACITY

This calculation done by Gladish (1976) is based on the capability of the shore from the 1.5 m depth to 0.6 km back from the lake to support recreational developments. It has been utilized in the Ontario Land Inventory surveys and the Ontario standards were used in this calculation.

The lake shore was classified into units of capability using topography, vegetation, offshore depth, bottom material and soil type. Each unit was measured to obtain a total accumulated distance for each rank. The number of cottages which can theoretically be supported in each rank were then totalled to obtain a development standard given in terms of cottage capacity.

According to Gladish's calculation, Sturgeon Lake has an optimum development capacity of 48 cottages. Since Sturgeon Lake already has 110 cottages on its shores, it is presently overdeveloped.

One of the assumptions made in this methodology is that the sewage facilities in use will be tile fields (Gladish, 1976). Since this system does not work well in clay soils and there are a lot of clay soil areas around the lake, the development capacity is low. However, cottagers presently using Sturgeon Lake are not using tile fields for sewage so the development standard is probably somewhat low. This may be balanced to some extent by the fact that there are 118 permanent residences within 300 m of the lake which have not been included in the capacity calculation.

5.3.3 BOAT LIMIT CALCULATION

Another development standard explored by Gladish (1976) uses the area of the lake surface to develop a space standard for using boats. The U.S. standards for recommended space requirements for boats ranges from about 1 acre for a fishing boat up to 40 acres for large pleasure craft or water skiing. It was assumed for the calculation that the average would be 10 acres per boat, as it was in the Ontario Land Inventory. The useable area of the lake was calculated by subtracting non-use areas from the total surface area. Non-use areas included areas further than 1.6 km from shore and areas close to the shore, access points, beaches and marinas.

Gladish estimated that the capacity of Sturgeon Lake for boats in terms of space only is 868. The assumption is then made that only 25% of the boats in the area would be on the lake at one time. Therefore, the capacity is actually 3472 boats or 520,000 user days per year (see 'user day' in appendix 5).

Gladish points out in his paper that in order to adapt this calculation to local conditions, some further refinements should be made. He recommends that a further 600 acres be deducted from the lake area to account for shallow shore waters and the aquatic vegetation. This lowers the calculated limit to 808 boats. I would also suggest that, since a large proportion of boaters using Sturgeon Lake are there on a daily basis, the assumption that only 25% of the boats are in use at one time is unrealistic. However, since it is a standard part of the calculation, it has been left in. Due to the limited number of access points, which causes congestion, and to increase the aesthetic appreciation of the boating experience on Sturgeon Lake, it is felt that

this capacity estimate is too high. C. Mack of the Peace River Planning Commission has suggested that half of the calculated value would be a more realistic estimate when local site conditions are taken into consideration (Gladish, et.al., 1975). I have, therefore, with consideration of the above factors, estimated the theoretical boat capacity of Sturgeon Lake to be 1616 boats or 242,000 user days per year.

5.3.4 WATER QUALITY INDEX

This method of calculating development capacity was also utilized by Gladish (1976). It is an expression of the sensitivity of the lake to increased nutrient input. The development level suggested is designed with the aim of maintaining the present trophic level of the lake. There should not, according to this method, be any effect of the use level on water quality.

The first step is to measure and score a number of water quality parameters in order to establish the present trophic status of the lake. These parameters are: mean depth, oxygen distribution, chlorophyll a, secchi depth, a morpho-edaphic index and the iron/phosphorus ratio. The Fe/P ratio is relevant only when the hypolimnion is anaerobic. The morpho-edaphic index is the ratio of TDS to mean depth at the 1.5 m and shallower depth.

Gladish's calculation placed Sturgeon Lake in the 'almost eutrophic' category which can theoretically support 20 users days per acre per year. This indicates a limit of 230,789 user days per year for the water of Sturgeon Lake to be unaffected by recreational use.

As the values used in this calculation for the parameters mentioned were close enough to those measured by the author in 1978 to get the

same rating in almost every class, this estimate has been accepted as it is.

5.3.5 DILLON AND RIGLER METHOD

This is a "technique for calculating the capacity of a lake for development based on quantifiable relationships between nutrient inputs and water quality parameters reflecting lake trophic status." (Dillon & Rigler, 1975, pg. 1519). The method of calculation is to first establish a permissable limit for mean summer chlorophyll a concentration or secchi depth. It is then possible to calculate what the permissable level of total P would be at spring overturn. By then estimating the total natural P load from all sources, it is possible to estimate the permissable artifical P load.

A calculation using this method for the Sturgeon Lake basin was done by Gladish (1976). He concluded that the natural P load exceeded the permissable limits and so, therefore, there was no leeway for artificial additions. For the most part, his calculations were completed satisfactorily, considering the available data base. However, there were a few places in which I have adjusted either the original data or the rationale behind using a particular figure.

The permissable average summer chlorophyll a which Gladish used was 7 mg m^{-3}. He chose this figure as an educated guess, based on the uses to which the lake is put and using Dillon's suggested levels of concentration. In fact, it was a very good guess if the management aim for the lake is to create a condition where P is the limiting nutrient. In 1978, the mean summer chlorophyll a concentration was 21.3 mg m^{-3}. The N:P ratio during the summer was 2.6:1 so in order

for P to be limiting rather than N (see section 5.2.4), P concentrations would have to be 2.8 times lower than they were in 1978. This lowered level would theoretically produce a mean summer chlorophyll a concentration of 7.6 mg m^{-3}. Therefore, the permissable figure which Gladish chose, if it was reached, would indicate that P was limiting. These calculations do not account for influences such as internal recycling of nutrients (see section 4.7.9).

Hickman (in press) has demonstrated that the equation developed by Dillon and Rigler to relate mean summer chlorophyll a to spring P concentrations did not work well for the more eutrophic type lakes. He pooled data from a number of sources and adjusted the original equation so that it would cover a larger range of trophic states. The new equation represents a curvalinear relationship between the two parameters and this is more applicable to eutrophic lakes where physical factors may become limiting. There is a maximum possible standing crop level after which decreased light penetration and self-shading inhibits further productivity, even if nutrients are still available. Using Hickman's equation, I calculated a permissable P supply for Sturgeon Lake of 5928 kg yr^{-1} as compared to the 8034 kg yr^{-1} calculated by Gladish.

In Gladish's calculation, he states that he has taken his P load from precipitation data from Ontario and suggests that these data may be wrong for the Sturgeon Lake area. On the basis of a couple of precipitation samples which I had analyzed for total P, I have to agree that his figure is too high. Although I do not have enough data to accurately establish a mean P value for precipitation in the area, it

is possible to use the data gathered by Trew, et.al. (1978) for Baptiste Lake. Since Baptiste Lake is in an area similar to that of Sturgeon Lake (ie. north central Alberta with little agriculture and no industry near by), it is reasonable to assume that mean P contents in precipitation would be similar. So, P from precipitation is estimated to be 33.2 mg m^{-2} yr^{-1} rather than 75 mg m^{-2} yr^{-1}. This lowers the natural P supply from 9365.7 kg yr^{-1} to 7746.8 kg yr^{-1}.

Since all other aspects of Gladish's calculation were accepted as being as accurate as the available data allows, we can now examine the outcome of the calculation. Table 13 shows the figures for the calculations by both the author and Gladish.

TABLE 13 P LOADING CALCULATED ACCORDING TO DILLON & RIGLER

	A[1]	B[2]
permissable mean summer chlorophyll a (mg m^{-3})	7	7
permissable total P at spring overturn (mg m^{-3})	23.38	17.29
permissable P supply (kg yr^{-1})	8034.0	5928.0
total natural P supply (kg yr^{-1})	9365.7	7746.8
total artificial P supply (kg yr^{-1})	357.0	357.0
total P supply (kg yr^{-1})	9722.7	8103.5
artificial supply as % of total supply	3.7%	4.4%

1 calculated by Gladish, 1976

2 calculated by author

Lack of data concerning the small lakes within the Sturgeon Lake drainage basin (ie. volume, area, etc.) have made it impossible to

calculate the effect of these lakes on the natural P supply. It is probable that these lakes retain some P which reaches them from their surrounding drainage basins. This would lower the natural P supply somewhat.

It should be recognized that this method of capacity calculation as presented by Dillon & Rigler does not account for all of the P sources to a lake. There is no calculation for inputs from waterfowl or livestock. Runoff from cropland, whether fertilized or unfertilized, is not included except as forest with up to 15% pasture. There is also no way to calculate P inputs caused by the disturbance of the land surface due to clearing or construction. The artificial sources of P are designed to account only for permanent residents and cottage users. Inputs from day use areas are not included. Since cottagers and residents accounted for only 51.7% of the total user days in 1977, inclusion of inputs from day users could prove to increase artificial supply substantially. All of these factors combined would increase the present estimate of artificial P load at Sturgeon Lake by several times.

From the data in table 13 it can be seen that the natural P supply exceeds the permissable supply for both calculations. Therefore, there would theoretically be no permissable artificial P supply. However, since some development by man has already occurred in the drainage area, there is an artificial P supply. Thus, the total P supply is already well above the permissable limits. This result was to be expected since the summer standing crop as measured in 1978 indicated that the lake was already producing more chlorophyll _a_ than that set as a permissable limit.

What is interesting to note is the relative contributions of the natural and artificial sources. According to this calculation, artificial supplies are only 4.4% of the total supply. If adjustments could be made as recommended, the natural supply would be lower and the artificial supply somewhat higher. This would seem to indicate that some diversion of P supplies may prove to have a beneficial effect on the waters of Sturgeon Lake, even considering the relatively high non-anthropogenic loading.

An interesting observation was made in the course of this calculation. In order to compare the calculated relationship between chlorophyll a and P concentrations with that actually measured, both points were plotted on the graph presented by Hickman (in press). Since the equation mentioned earlier in this section can also be used to predict the chlorophyll a concentration from the measured spring P concentration, this calculation was also done. What was found was that the P level in Sturgeon Lake should theoretically support 80% more chlorophyll a. In other words, with a spring P concentration of 680 mg m^{-3}, Sturgeon Lake should have had 104.8 mg m^{-3} chlorophyll instead of only 21.3 mg m^{-3}. The fact that it didn't indicates that physical factors such as high turbidity and color are limiting higher primary productivity. The nutrients are there but they are not being fully utilized. So any attempts to limit primary productivity by limiting the required nutrients would have to cut the supply of P drastically before there would be any effect.

5.3.6 COMPILED CAPACITY RECOMMENDATIONS

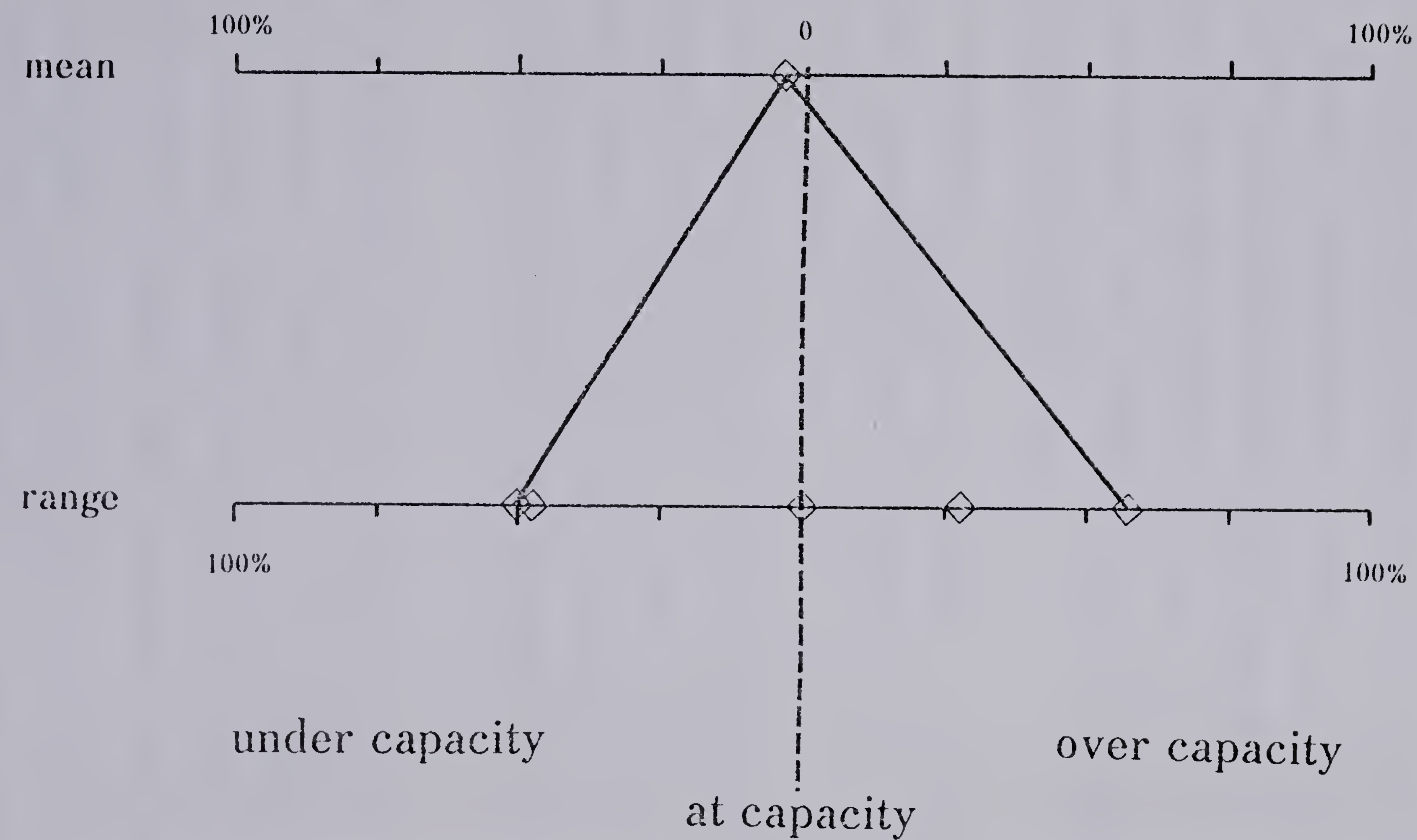
In a paper by Jaakson, et.al. (1976), several carrying capacity calculations were made, much as they were here. To provide a means of

getting an overall view of the results as well as to compare the relative result of each calculation, they recommend calculating a percentage value of over or under development for each method and presenting the results schematically. The results of this are presented below and in figure 27 which depicts the mean and range of this calculation.

1. User Survey			
recommended:	120,000 days		
present development:	120,000 days		$\pm 0\%$
2. Shoreland Capacity			
recommended:	48 cottages		
present development:	110 cottages		+56.4
3. Boat Limit			
recommended:	242,000 user days		
present development:	120,000 user days		-50.4
4. Water Quality Index			
recommended:	230,784 user days		
present development:	120,000 user days		-48.0
5. Dillon & Rigler			
recommended:	5928 kg yr^{-1} P supply		
present development:	8104 kg yr^{-1} P supply		+26.8
			-15.2%
		mean	-3.0%

Thus, Sturgeon Lake appears to be very slightly underdeveloped at present. In the opinion of the author, there is something valid in what each one of these calculations indicates. The shores of Sturgeon Lake probably should not be developed any further. There is presently a pleasing environment aesthetically and access is relatively good. Both the boat limit and the water quality index indicate that the lake could stand half again as much recreational use. So long as this use

FIGURE 27 CAPACITY CALCULATIONS - SCHEMATIC REPRESENTATION



Source: Author

was in well planned public access areas, it is feasible. The phosphorus loading calculation of Dillon and Rigler indicates overuse but due to the large natural inputs this would be almost impossible to control. However, the warning should be noted and every attempt to keep the lake from being recipient to more nutrients than is necessary should be made.

5.4 LAKE LEVELS

The outflow for Sturgeon Lake has had dams controlling lake levels since 1949. The original dam was replaced in 1969 by a fixed crest structure with a gate opening which allows a discharge of up to $0.42\ m^3\ s^{-1}$ when the lake level is below the crest of the dam. The purpose behind the structure is to provide the town of Valleyview with a reliable water supply (see section 3.10.5).

In attempting to rationalize building the structure as a multi-purpose project, Dean (1968) stated that it would "provide stricter control of flooding around the lake during periods of high runoff." In actual fact, dams are only useful for controlling flooding downstream of the structure. Since this structure was built to control low water flows, it would not be very effective for flood control when lake levels are above the crest of the dam during extreme runoff events even for downstream areas.

Dean also presents a cost-benefit analysis for the structure which is skewed in favor of the project. He presents benefits which range from purely economic to purely aesthetic but on the cost side of the analysis he discusses only the monetary costs of building the structure.

Due to the make-up of the dam, it has a very limited capacity to lower high lake levels and the natural channel capacity has been reduced

so that high water levels upstream are prolonged. The channel capacity is further restricted when sediments settle out of suspension on the upstream side, gradually building into a sand bar. This sand bar has already been dredged out once to increase the flow capacity.

As there are no data on lake levels prior to the controlling of the lake outflow, it has not been possible to establish what natural lake level fluctuation was. After the second dam was built in 1969, lake level data over the five year period immediately following shows a maximum variation of 1.26 m. The high water mark of 677.6 m ASL in June 1974 was 0.8 m above crest level and the low level of 676.4 m ASL in November 1970 was 0.5 m below crest level. In a lake such as Sturgeon which has a gently sloping shore and lake bottom, this magnitude of fluctuation is quite large.

It seems likely that natural fluctuations were also in this order of magnitude. The difference in this case is that the high levels are higher than they would have been naturally. In some stretches of beach, this is an advantage. However, long stretches of shore are subjected to increased bank erosion due to the higher levels (see photo 8). The potential for shore erosion by wave action also increases. There are also a number of areas where good sand beaches are flooded for most of the year.

High water levels may also raise the water table in the land around the lake, particularly where lake waters are an extension of the ground water table. This can create problems with sewage systems in the area which would then increase the nutrient load in the lake. This may not be the case at Sturgeon Lake but since there are some springs near the

PHOTO 8: HIGH LAKE LEVEL UNDERCUTTING SHORELINE VEGETATION AT SAMPLE SITE B.

PHOTO 9: LARGE AMOUNTS OF MACROPHYTE GROWTH AT SAMPLE SITE I.

lake shores, it is likely that there are some interactions between the two water systems.

It was speculated by Bishop (1971a) that stabilizing the lake level would be beneficial to the fish populations in the lake. However, it has never been ascertained whether or not those benefits did result. Some people in the area, including Dan McLean, chief of the Indian Band, feel that the control structure has had an adverse affect on the fish populations. Theoretically, raising the lake level would increase D.O. concentrations, reducing fish kill incidents. However, it is during the winter when hypolimnetic oxygen is low that the water levels are drawn down to supply water to the town. Also, the dam has been hampering fish migrations since its installation.

Obviously, there have been some problems with the control structure on Sturgeon Lake. However, as it is necessary to maintain a water supply for Valleyview, it cannot simply be removed. There are at least two alternatives that may be utilized to deal with these problems. One is to find an alternate water source for the town and the other is to supply more upstream storage above Sturgeon Lake. Both of these alternatives will be discussed more fully in chapter 6.

5.5 VISUAL IMPRESSIONS

Algae and weeds in a lake are visual evidence of eutrophic conditions resulting from the presence of abundant nutrients which support plant and animal life.

Underwater macrophyte growth was first noted at site I on May 28. By June 4, lily pads had begun to float on the surface at the same site. The next site at which macrophytes were observed below the water's

surface was E on June 11 and by June 25 they were obvious at all of the sites. Emergent flower blooms began to appear on July 3 and continued to flower until August. Submerged, floating-leaved and emergent macrophyte growth continued through August until a 100 to 250 m band of vegetation lined the lake shore. Figure 28 has been drawn to show the distribution of emergent and floating leaved macrophytes around Sturgeon Lake. In photo 9 it is possible to see some of the macrophyte growth at site I where the weeds were so thick by the end of June that the boat motor could not be used. Species of macrophytes which are commonly found in Sturgeon Lake include cattail (*Typha*), bulrush (*Scirpus*), arrowhead (*Sagittaria*), water lily (*Nymphaea*), pond weeds (*Potamogeton diversifolia* and *Potamogeton pectinatus*) and muskgrass (*Chara*).

Phytoplankton first became apparent visually on June 11 at sites B, D and G. By early July, bloom conditions were noted over the whole lake and a dense scum formed on the water surface in the eastern half of the main lake basin. This bloom was dispersed within a week but another bloom formed by August 3, this time in all parts of the lake but particularly sites C and I. A scum was also formed by this bloom. Algae populations appeared to decline from mid-August into the fall.

It was also observed that some of the recreation areas were showing signs of wear. For example, the banks of Goose Creek near the mouth are frequented by large numbers of fishermen. Much of the undergrowth has been destroyed and increased erosion has resulted. This also seems to be occurring on the shores of Sturgeon Creek, although in that location it is difficult to pinpoint clearly because the materials dredged from the creek channel have been dumped right on the creek

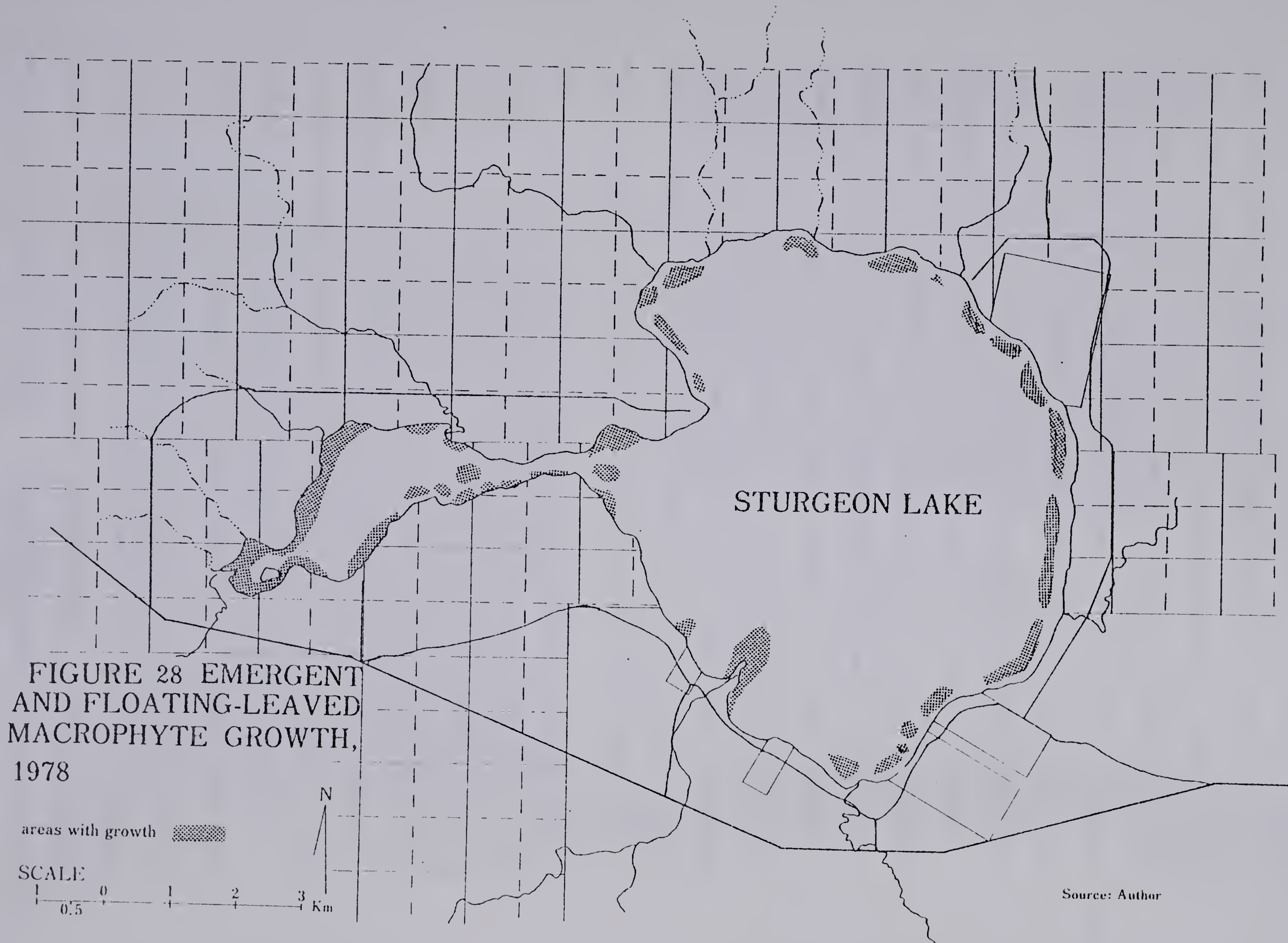


FIGURE 28 EMERGENT AND FLOATING-LEAVED MACROPHYTE GROWTH, 1978

bank. Some shore areas which are utilized for fishing and camping are occassionally littered with trash. The boat launch areas at Williamson Park and Cozy Cove are well maintained and show few signs of erosion problems. However, the boat launch at Sandy Bay has not fared as well and requires some attention (see photo 10). There is also a problem with the boat dock at Sandy Bay. The cottage owners there require a sheltered spot to tie up their boats since the prevailing winds frequently cause large waves to buffet the shore. However, rather than follow proper procedures and build a sound, well-planned shelter, they merely dredged out the mouth of a small creek nearby (photo 11). This shelter immediately began to fill with sediment and is rapidly losing its usefulness. In spite of these problems, Sandy Bay has much less visual impact from the lake than Boyd's Co-op does. This is because the former is set back behind a vegetation screen while the latter is a row of cottages along the shore (photo 12).

Cattle grazing is causing some problems in the Sturgeon Lake area. A feed lot on the extreme west end of the lake is situated on a slope which drains directly into site I. This may be helping to aggravate conditions in a natural nutrient trap area and use of the land for cattle grazing should probably be discontinued. Another problem area is on Goose Creek. At site K, a cutline crosses the creek. Although the area was once fenced off, it now has open access to a herd of cattle which is maintained on a field bordering the creek. The bank of the creek shows severe trampling by the cattle (photo 6) which is causing an erosion problem. Livestock manure is a readily available source of N, P and Cl which usually moves freely into water supplies (Robertson and McQuitty, 1978). It has been estimated that the nutrients

PHOTO 10: BOAT LAUNCH AT SANDY BAY, SAMPLE SITE C.

PHOTO 11: BOAT DOCK IN STREAM MOUTH AT SANDY BAY, SAMPLE SITE C.

PHOTO 12: LINEAR SHORELINE COTTAGE DEVELOPMENT AT BOYD'S CO-OP, SAMPLE SITE G.

released due to one cow are equivalent to those released by 10 people or from 5 cottages (comments by C. Mack in Gladish, 1976). Regulations exist to restrict this kind of access by cattle to surface waters; they need only be enforced.

In general, Sturgeon Lake is an attractive and pleasing lake environment. Except for the periods when algal scum coats the water, the lake is an appealing recreational resource.

5.6 SUMMARY OF CONCLUSIONS

The main conclusions which were reached in the course of this study are summarized in point form below. The implications of these results and recommendations for possible management alternatives are dealt with in chapter 6.

1. Lake circulation is controlled mainly by wind induced currents and is highly variable.
2. There have been no significant changes in water quality in the last ten years.
3. Most of the nutrient influx to the lake is via Goose Creek (site E) from the upstream wetlands.
4. The western arm of the lake has a lower quality of water than the main basin.
5. From the data gathered at Sturgeon Creek (site D), it appears that most of the nutrients which are entering the lake are staying in the lake.
6. Spatial and temporal variations in water quality are presently attributed mainly to natural causes.
7. Total phosphorus is above the recommended limits, as it is in many Alberta lakes.

8. Nitrogen appears to be the limiting nutrient, therefore blue green algae populations are favored.
9. In fact, neither nitrogen or phosphorus is actually limiting. Primary productivity is limited by physical factors rather than by nutrients.
10. Sturgeon Lake is in a mildly eutrophic condition.
11. Development capacity calculations indicate that a slight increase in recreational use is possible if it is well-planned and managed. Shoreline development is already at or over capacity.
12. Shoreline erosion indicates that spring lake levels are maintained at an excessively high level for a prolonged time period.

CHAPTER 6

MANAGEMENT ALTERNATIVES AND RECOMMENDATIONS

In 1977, part of Sturgeon Lake was chosen, along with 13 other lakes, to be designated by the Alberta government as a restricted development lake. The purpose behind this was to control the development of shorelands until such time as an acceptable land use plan was presented and passed into bylaws.

The general planning approach is to first compile a resource inventory in order to establish the potential of the area for various uses. Then, taking into account the demand for use and the development capacity of the lake, a development plan may be drawn up. Prior to this study, there was a lack of water chemistry data on which to base the rest of the plan. Now that these data have been gathered and analyzed, it is possible to discuss the directions which management could effectively take. The final step in this study will be to compare the recommendations made on the basis of this new data base with those which were made in the management plan submitted for approval by the planning authority responsible for the Sturgeon Lake area, the Peace River Regional Planning Commission.

Sturgeon Lake presently provides a varied and enjoyable recreational experience. The goal is to continue to provide that kind of experience to as many people as possible without causing the lake to accelerate into a more eutrophic, less useful condition.

6.1 MANAGEMENT ALTERNATIVES

On an abstract level, there are four general courses of action which

are open to any lake management plan: increased use, stabilized use, constrained use or decreased use. It is also important to note that rehabilitation of lakes is a very difficult and expensive process. Whenever possible, measures designed to prevent degradation of the resource should be implemented.

6.1.1 LAND USE ZONING

As has been demonstrated in chapter 4, any changes in the watershed of a lake will ultimately have an effect on the lake itself. Different land based activities produce distinctly different hydrologic responses. A large portion of the nutrients and sediments which enter surface water systems become available for transport as a result of disturbances to the land. The effect of land use change on water quality is threefold. The change initially disturbs the land surface and makes it more susceptible to erosion. The hydrologic response is modified so that more overland flow is available to carry out the erosion and transport the materials (see section 3.7.1, water balance). And the land use itself, once begun, may contribute more nutrients than the initial land use did.

There are seven categories of land use which may be considered in the case of Sturgeon Lake. These are: public recreation including day use areas, campgrounds and boat launching sites; commercial recreation including stores, rental cabins and marinas; private recreation at cottages and on private land; permanent residences on the reserve and at Calais and Sturgeon Heights; transportation; nature conservation including aquatic and terrestrial vegetation, water quality and effects on fish and wildlife; and resource extraction and/or development

which includes agriculture, livestock grazing, oil and gas extraction, fishing and forestry.

A major shift in land use from forest to cleared land would have a substantial effect on the lake. Cleared land contributes about five times more phosphorus than the same area would under forest cover (Mitchell, 1979a). This is because a decrease in soil moisture storage leaves more surplus for runoff (Martz, 1979) and the runoff is flashier in nature (Erxleben, 1972). Both forestry operations and petroleum development increase erosion (Environmental Conservation Authority, 1976; Bliss & Peterson, 1973; Pierce et.al., no date). Recreation and transportation developments have fewer prolonged impacts on the hydrologic responses but do create similar effects during the construction period. Erosion from road construction may increase sedimentation by up to 750 times compared to a similar undisturbed watershed with the effects being felt for up to six years after construction (Groenewoud, 1977).

Therefore, any proposals to develop land anywhere in the watershed should be carefully considered in terms of the effect thay they may have upon the lake. Good setbacks from all streams should be rigorously enforced and any particularly fragile or erodable areas should be zoned as conservation areas (eg. the land around the west arm of the lake).

There are a number of ways of ameleorating problems which are being caused by land uses which are presently active in the area. One is to institute a program of direct purchase of easements in sensitive areas. Another is to provide incentives to land disturbers to

implement management practices which would reduce non-point pollution. The Fish and Wildlife Division of the Alberta government has introduced a program which is aimed at protecting streams which cross private lands by fencing streams, providing special watering sites for livestock and providing gates and appropriate crossings as required. This kind of program is desirable in problem areas such as site K on Goose Creek.

At present in the Sturgeon Lake area, the land use which seems to be causing the most problems is cattle grazing. Two of the areas in which this is occurring are also the areas in which water quality is the worst. Although the latter is apparently not a direct result of the former, the situation is not helping matters any. The area at the extreme west end of the lake should be purchased as an easement and maintained as a conservation area. At the other site on Goose Creek, access to the stream by cattle should be prevented.

The impacts of oil and gas developments are not as clearly defined but they are probably worthy of consideration, especially in view of the numbers of roadways which have been built. The oil fields (as shown in figure 18) are quite large and there is likely to be an increase in the number of oil and gas well sites. The location and access development of any new wells should be carefully considered to minimize the impact.

There are no forestry operations currently active in the drainage basin but there is a lease to the north of the lake. Future clear-cutting of that area would have a large and undesirable effect on the lake. Strict regulation of any future forestry operations is

recommended.

The use of vegetation buffers should be encouraged on slopes which require some stabilization and along all stream and lake shores. Since geologic, topographic and edaphic features are more or less fixed characteristics of an area, the vegetative factors are the main avenues for exerting any modifying influence. A vegetative cover helps to reduce erosion by wave action as well as reducing raindrop impact, slowing runoff and increasing soil moisture storage and soil infiltration. These greenbelts act as natural preservers of water quality by trapping and using nutrients which would otherwise enter the lake. A number of studies have been done to establish the effectiveness of greenbelts in minimizing the effects of forestry operations on surface waters. It has generally been found to be very effective and buffer zones of from 15 to 20 m for fairly level terrain to 65 m for moderately sloping terrain have been recommended for use (Groenwoud, 1977). As an interim measure to control agricultural runoff until such time as easements can be purchased, the planting of vegetation buffer zones could prove to be beneficial. The areas which most need this are at the west end of the lake along the farmed land, on the south shore near the Mission Church and along some of the residential sections of the Indian reserve.

6.1.2 WATER SURFACE ZONING

In a lake such as Sturgeon Lake where it is desirable to maintain a fishery and wildlife resource as well as to meet recreational demand, it is sometimes necessary to restrict the operation of motor boats in areas that are important for fish spawning or wildlife habitat. On

the basis of studies by Bishop and observations made by the author in the field, the areas around the mouths of Goose and Sturgeon Creeks and the western arm of the lake should have some restrictions on use, perhaps even to the point of eliminating motors altogether.

6.1.3 NUTRIENT INPUT CONTROL

Relatively shallow lakes such as Sturgeon Lake are usually quite sensitive to increased nutrient input (Brezonik, 1972). Likewise, after nutrients have been diverted, thus reducing the nutrient load, recovery by a shallow lake will be slow. This is due to the effects of sediment recycling of nutrients, whether as a result of anaerobic release of nutrients or the stirring up of the sediments themselves by wave action. However, without the diversion of nutrients, the lake would get worse. As productivity and standing crop increase, the demand for oxygen will also increase, especially in the winter hypolimnion. Since lakes naturally act as nutrient traps, the internal recycling system in the lake will gradually increase in importance until the nutrients reach a level of saturation. Then physical factors such as decreased light penetration will limit further productivity.

As was demonstrated in chapter 5, primary productivity in Sturgeon Lake in the summer of 1978 was apparently limited by physical factors. There is much more phosphorus in the lake than is being utilized and there is a limitless supply of nitrogen in the atmosphere. Since the phosphorus entering the lake is largely from natural, non-point and virtually uncontrollable sources, and since the phosphorus already in the lake could be readily available for recycling if outside

sources were reduced, the possibility of creating a situation where phosphorus is limiting is indeed remote. Therefore, it is unlikely that controlling nutrient inputs will improve the condition of the water. However, this should not be interpreted as being a carte blanche to release excessive amounts of wastes into the lake. The exact physical limitations which were placed on productivity in 1978 were not clearly established and may not be consistently present. The severity of the Anabaena bloom appears to vary greatly from year to year, sometimes being widespread and prolonged enough to cause massive fish kills (eg. June, 1969)(Bishop, 1977a). It may be that in some years, the nutrient saturation point is different from other years. In order to at least maintain the present condition of the lake, it seems reasonable to try to keep nutrient inputs to a minimum. This means controlling waste discharges and land use practices. Areas in which it is possible to control inputs are cattle grazing, crop-lands, campgrounds and cottages. Methods of controlling inputs from agricultural sources have been discussed in section 6.1.1. Control of recreational inputs would involve having a reasonable set back for dwellings, well planned access points and efficient sewage facilities (possibly pump-out systems).

6.1.4 IMPROVED FOOD CHAIN RELATIONSHIPS

An alternate means of dealing with the problem of high nutrient levels in a lake is to improve the food chain relationships. At Sturgeon Lake, this would entail finding a method of controlling the populations of blue green algae as it is this population which forms the scum on the water surface and seems to be associated with the fish kill occurrences. If a situation could be created where green algae,

which are present in the lake in early summer, could maintain a position of dominance, then the condition of the lake would probably improve. Green algae are more desirable than blue green algae because they do not form a surface scum and they are more amenable to grazing by zooplankton and fish.

In a study conducted by Shapiro (1973), it was found that a shift from blue green to green algae domination could be initiated by adding carbon dioxide to the water and/or lowering the pH levels. The shift was even more dramatic when nutrients were added at the same time. Unless the additions were continued, it is likely that a shift back to blue green dominance would occur as the CO_2 supplies were once again lowered to critical levels. However, it may be possible to set up an artificial aeration system which only injected CO_2 to the lake waters (Shapiro, 1973). This, with the addition of a nitrogen fertilizer or conjunctive draining of low pH wetlands, may be enough to maintain a dominance of green algae.

The possibility of installing an artificial aeration system at Sturgeon Lake was examined once before (Gladish, et.al., 1975) and was found to be too expensive. It was also unnecessary in terms of the normal use of an aeration system since Sturgeon Lake is not generally thermally stratified in the summer so hypolimnetic dissolved oxygen is not a problem. However, the injection of CO_2 to the lake is another idea altogether. It is likely that, at the present time, the use of this system would not be economically feasible. Another drawback is that the idea has not yet been tested on a whole lake. However, if blue green algae populations continue increasing to a point where

the fishery and recreational resources are in jeopardy, this may prove to be a feasible method of dealing with the problem.

6.1.5 WETLAND DRAINAGE

The possibility of improving watershed conditions by draining wetland areas was examined. This procedure could improve the land use potential in the basin considerably (Mustonen, 1976) but, if it was not carefully controlled, it would not be as beneficial to the lake itself. Uncontrolled drainage would release large amounts of nutrients and sediments to the lake in a short time period. If all of the recovered land was levelled and cleared for agricultural use or the construction of buildings, it would increase the runoff regime and the nutrient input would stabilize at a high level since the filling in of wetlands would result in a loss of nutrient traps.

Still, there is some potential for controlled drainage. Small scale periodic drainage directly to the lake would probably not have a significant detrimental affect on the lake waters. In fact, it may prove to be beneficial since wetland waters have a low pH and the higher acidity could improve growth conditions for green algae (see section 6.1.4).

The area immediately south of the Narrows is very marshy and of no present use value, even for waterfowl. If this was drained into the main basin of the lake, it may be possible to develop the land into an extensive recreation area. Access to the lake itself for recreationists would be at Williamson Provincial Park. The proximity of a beach makes this site a good choice for potential development. Drainage should be to the main basin rather than the western arm until

tests are done to indicate the effects of the process on the lake water. Since the main basin has a lower nutrient retention potential it is a less fragile site. Particular attention should be paid to pH levels when changes in water quality are monitored. Proof that there is a significant lowering of pH and an increase in green algae dominance over blue green algae could make wetland drainage to any part of the lake a feasible lake restoration technique.

There are two other areas where small scale drainage experiments may be carried out. Some of the marshy areas north west of the western end of the lake and another area to the south near the two small, semi-connected unnamed lakes could potentially be drained to the west. Drainage out of the basin is recommended until such time as it is proved that the effect would be beneficial to the western arm area. If the drained water was directed to Cornwall Creek it would move quickly into the Simonette River and would not immediately enter another lake. The northern site could be used for private cottage development as access to the lake via Young's Point Provincial Park is quite convenient. The southern area would be better reserved as a conservation area with drainage returned to its natural course into Sturgeon Lake. This test site could then be studied to observe the subsequent changes in drainage quantity and quality.

6.1.6 LAKE RESTORATION TECHNIQUES

Other than the artificial aeration systems discussed in section 6.1.4 and the potential value of wetland drainage discussed in section 6.1.5, there are two other methods of lake rehabilitation which may be utilized.

The dredging of lake sediments to remove in-lake nutrients has proven to be successful for some Swedish lakes (Björk, 1972a, Björk, 1972b; Björk, et.al., 1972). However, it was a very costly procedure, even when implemented for the Swedish lakes which are much smaller than Sturgeon Lake.

The second method is to control aquatic vegetation growth by either chemical, biological or mechanical means. Chemical control of weed growth can prove to be more harmful than beneficial and is not allowed in lakes which support a commercial fishery. Biological control of aquatic plants is possible in some cases but does not appear to be viable for Sturgeon Lake. Swans have been successfully introduced to control weed growth in small ponds but this lake is too large and conflicts would undoubtedly arise between boating and the birds. White amur have also been found to be effective in reducing macrophyte growth but the introduction of new fish species to Alberta lakes is illegal. So, any aquatic vegetation control would have to be by mechanical means. This is a viable method of vegetation removal, as has been demonstrated at Lake Wabamun, but should be carefully regulated. Littoral zone vegetation is important as spawning and feeding areas for fish. It also acts as a nutrient sink for incoming surface runoff. Large scale macrophyte control is not recommended. However, removal of small areas of growth in beach and boat launching areas would increase the enjoyment of these activities. Any vegetation that is cut or pulled up should be removed from the lake completely.

6.1.7 OTHER MANAGEMENT RECOMMENDATIONS

In terms of the present recreational use of Sturgeon Lake, there are

two minor recommendations. One is that the boat launch and dock at Sandy Bay be improved. The other is that trash receptacles be placed at popular fishing spots to encourage the maintenance of a clean environment. These actions, in conjunction with water surface zoning, would do much to enhance the environment around the lake.

It should also be noted that when the channel upstream of the existing dam is dredged clear, the sediments which are removed should be deposited some distance from the lake and not right on the shore of the creek. Nutrients which are removed from the lake in this sediment are leached directly back into the lake when the deposits are left so close to the shore.

In section 5.4, it was mentioned that there are a couple of possible methods of ameliorating the effects of the control structure located on Sturgeon Creek. If lake managers for the area agree that spring water levels are high for too long and wish to make the flooded beaches available earlier in the season, then it is desirable that a solution to the problem be found. One way of doing this is to build another control structure upstream on Goose Creek. This would help to provide storage for surface runoff during high flow periods such as spring melt and keep enough water back to maintain a steady water supply for the town of Valleyview without flooding the shores of Sturgeon Lake. The only other way to lower the lake level would be to remove the control structure on Sturgeon Creek. This would make it necessary to locate an alternate water supply for the town or to find a way of maintaining sufficient discharge in Sturgeon Creek during low water periods. A dam on Goose Creek or controlled wetland drainage could be regulated

to maintain a minimum lake level during dry years. The unpredictable nature of weather patterns could make the wetland drainage alternative difficult to plan and replacing one dam with another is not very practical economically. Therefore, it would be better to find alternate water sources for Valleyview that could be used to supplement the Sturgeon Creek supply. This would involve developing an integrated supply plan for the town. Water sources could include Sturgeon Creek, groundwater supplies and wells with induced infiltration on the alluvial terraces of the Little Smokey River. The combined potential of these sources would have to be carefully studied but preliminary data indicates that this may be a viable alternative.

6.2 GENERALIZED SUMMARY OF RECOMMENDATIONS

On the basis of the development capacity calculations presented in this study, it appears that Sturgeon Lake has almost reached the optimum level of development. However, demand for recreational use of the lake is bound to increase so a management plan must be prepared to cope with this. It is not likely that the lake would be greatly affected by a moderate and well planned increase in use. Large scale private cottage development along the lake shore, such as that commonly found in Ontario, is not desirable for both aesthetic and environmental reasons. Greatly increased use involving large amounts of construction and contributing a continued high waste discharge could jeopardize the commercial fishery in the lake. However, some cottage development with lake access via public beach areas could be extended to the recommended backshore areas. Other than the areas suggested for development in conjunction with wetland drainage, there are very few backshore areas that are amenable for development which

also have good access to the lake. One possible site is east of the lake just outside the drainage basin. Construction in this area would not affect the lake directly since drainage would be to Sturgeon Creek downstream of the lake. The area is close to the lake and a boat launch and beach area could be developed on the east shore. This boat dock area could then be made available to the Girl Guide and Navy League camps. It would be necessary to include a breakwater on this beach since the prevailing wind makes the water along this shore very rough most of the time. However, at present and near future use levels, the existing access is sufficient.

As much of the shoreland as possible should be maintained as natural areas for aesthetic and conservation reasons. Any construction and resource use or development should be carefully controlled to minimize the impact. Stream channels should be protected in all areas. Extensive, low-impact recreational developments such as walk-in camp sites, horse trails, hiking trails and nature centers in the backshore areas would provide alternate recreational activities. These activities are planned for Young's Point Provincial Park but, when this area reaches an optimum use level, alternate areas should be developed.

6.3 SUGGESTIONS FOR FURTHER STUDY

In the course of this study, a few areas in which data are lacking have been noted. These may be of interest as research topics.

A water quality monitoring program for Sturgeon Lake that will include winter samples and will last for a period of at least two years has recently been started by the Water Quality Control Branch of Alberta

Environment. This program will be useful in establishing annual patterns and variations. Special attention should be paid to whether or not primary productivity is always limited by physical factors and, if so, what those factors are and how they vary.

The proposed wetland drainage projects could be initiated and monitored to determine the effect on the lake waters, particularly in regard to pH levels and algae populations.

The recommendation that an integrated water supply for Valleyview be examined could provide an interesting study topic.

The proposed management plan for Sturgeon Lake which was prepared by the Peace River Regional Planning Commission (1978) is sound and well oriented in terms of the findings presented in this study. However, their plan deals only with the area immediately surrounding the lake. Since the quality of lake water appears to be related directly to natural environmental factors and the influence of these factors is from the whole basin, it is desirable that a management plan for the whole basin be drawn up. As recreational use demand increases, development pressures which presently focus on the lake shores will simply move outside the limits of the present management plan. The planning commission should be prepared to direct these pressures to the areas which will best accommodate them.

The last topic that I will suggest is more of a general research proposal and would be a large scale project. It involves experimenting with the idea of adding carbon dioxide and nitrogen to lakes with high phosphorus concentrations that are dominated by blue green algae to test out Shapiro's (1973) findings in a whole lake system. Studies

similar in scale have been conducted in the Experimental Lakes Area of Ontario (Schindler, 1974). It is important that tests on this scale be conducted in some small Alberta lakes. Conditions here are very different from those in Ontario and, in order to better deal with our limnological problems and to provide knowledgable advice for lake managers, it is necessary that active local experience be gained.

REFERENCES

Abiodun, A.A., 1976. Space Survey of Particulate Distribution Patterns in Lake Kainji. Remote Sensing of the Environment 5(2): 109-123.

Addison, Herbert, 1946. Hydraulic Measurements - A Manual for Engineers. John Wiley and Sons, Inc., New York.

Alberta Agriculture, 1976. Alberta Farm Guide. Government report, Edmonton.

Alberta Dept. of Health, 1968. Recommended Standards for Water Supply and Sewage. Environmental Health Services Division, Edmonton.

Alberta, Government and University of, 1969. The Atlas of Alberta. Edmonton.

Albota, M. and D. Rosca, 1976. Establishment of the Hydro-morphometric Characteristics for Water Bodies Using Photogrammetric and Remote Sensing Recordings. Int. Soc. for Photogrammetry XIII Congress, Helsinki, July 11-23, 1976.

Alexander, Vera, 1970. Relationships Between Turnover Rates in the Biological Nitrogen Cycle and Algal Productivity. Purdue University Engineering Extension Series, No. 137.

American Chemical Society, 1971. Cleaning Our Environment - The Chemical Basis for Action. Report by the Subcommittee on Environmental Improvement, Government Printing Office, Wash., D.C.

American Public Health Association, 1936. Standard Methods for the Examination of Water and Sewage. New York.

American Society for Testing and Materials, 1966. Water Quality Criteria. Special Technical Publication No. 416, Phil., Pa.

American Water Works Association, 1950. Water Quality and Treatment. New York.

Anderson, Mills, 1975. Sturgeon Lake Control Structure Modifications. Environmental Engineering Support Services, Alberta Environment, Edmonton.

Anderson, R. Stewart, 1974. Diurnal Primary Production Patterns in Seven Lakes and Ponds in Alberta (Canada). Oecologia (Berl.) 14: 1-17.

Anonymous, 1972. Fish That Weed the Waters. Agr. Research 20(11): 6-7.

Arveson, J.C., J.P. Millard and E.C. Weaver, 1971. Remote Sensing of Chlorophyll and Temperature in Marine and Fresh Waters. Mimeograph copy from the Canadian Center for Remote Sensing.

Atkinson, T.C., D.I. Smith, J.J. Lavis and R.J. Whitaker, 1973. Experiments in Tracing Underground Waters in Limestones. Journal of Hydrology 19: 323-349.

Bailey-Watts, A.E., 1976. Planktonic Diatoms and Some Diatom-Silica Relations in a Shallow Eutrophic Scottish loch. Freshwater Biology 6: 69-80.

Bannerman, R.T., D.E. Armstrong, R.F. Harris and G.C. Holdren, 1975. Phosphorus Uptake and Release by Lake Ontario Sediments. National Technical Information Service, U.S. Dept. of Commerce Ecological Research Series.

Bannister, T.T., 1974. A General Theory of Steady State Phytoplankton Growth in a Nutrient Saturated Mixed Layer. Limnol. Oceanogr. 19: 13-30.

Barica, Jan, 1974. Some Observations on Internal Recycling, Regeneration

and Oscillation of Dissolved Nitrogen & Phosphorus in Shallow Self-contained Lakes. Arch. Hydrobiol. 73(3): 334-360.

Bauer, Wolf, 1978. Lake-Shore Classification. Mimeograph copy.

Beasley, R.P., 1972. Erosion & Sediment Pollution Control. Iowa State University Press, Ames, Iowa.

Bella, David A. and Philip A. Meyer, 1978. Managing Uncertainty On the Shore. Shore Management Symposium, Canadian Council of Resource and Environment Ministers, Victoria, B.C.

Bellinger, D.F., 1975. Canadian Water Management Policy Instruments - Outline for OECD Water Management Sector Group. Environment Canada, Inland Waters Directorate, Water Planning & Management Branch, Social Science Series No. 13, Ottawa.

Benton, A.R. and R.M. Newnam, 1976. Remote Sensing Analysis of Lake Livingston Aquatic Plants. Reprint from the Canadian Center for Remote Sensing.

Bhagat, Surinder K., Donald E. Proctor and William H. Funk, 1970. Sampling & Measurement in the Aquatic Environment. Purdue University Engineering Extension Series No. 137: 98-111.

Bishop, F.G., 1971a. Limnology and Fisheries of Sturgeon Lake, Alberta 1969-1970. Fish and Wildlife Division, Dept. of Lands and Forests, Edmonton.

Bishop, F.G., 1971b. Goose Creek Survey, 1971. Fish and Wildlife Division, Dept. of Lands and Forests, Edmonton.

Bishop, F.G., 1973. Observations on the Sturgeon Lake Whitefish Fishery. Fish and Wildlife Division, Dept. of Lands and Forests, Edmonton.

Bishop, Frank G., 1977a. Sturgeon Lake Creel Census & Biological Survey Program - Summer, 1976. Fish and Wildlife Division, Dept. of Recreation, Parks & Wildlife, Peace River, Alberta.

Bishop, F.G., 1977b. Some Comments on the Sturgeon Lake Commercial Fishery Since the Reintroduction of 5½" Mesh Size. Fish and Wildlife Division, Dept. of Recreation, Parks and Wildlife, Peace River, Alberta.

Bishop, F.G. and D.G. Schroeder, 1972. Goose Creek Survey, 1972. Fish and Wildlife Division, Dept. of Lands and Forests, Edmonton.

Bliss, L.C. and E.B. Peterson, 1973. The ecological impact of northern petroleum development. Fifth Int. Congress, Arctic Oil & Gas: Problems and Possiblities, Le Havre, France, May 2-5, 1973.

Björk, Sven, 1972a. Bringing Sick Lakes Back to Health. Sartryck ur Teknisk Tidskrift 11: 1-7.

Björk, Sven, 1972b. Swedish Lake Restoration Program Gets Results. Ambio 1(5): 153-165.

Björk, Sven, Lars Bengtsson, Hans Berggren, Gertrud Cronberg, Gunnar Digerfeldt, Siegfried Fleischer, Curt Gelin, Gunilla Lindmark, Nils Malmar, Folke Plejmark, Wilhelm Ripl and Per Olof Swanberg, 1972. Ecosystem Studies in Connection with the Restoration of Lakes. Verh. Internat. Verein. Limnol. 18: 379-387.

Borengasser, Michael J., 1978. A Daily Water Budget for Estimating Runoff. AAG Meeting, New Orleans, April 9-12, 1978.

Born, Steven M. and Douglas A. Yanggen, no date. Understanding Lakes and Lake Problems. Reprint of a report.

Bortleson, Gilbert C. and G. Fred Lee; 1974. Phosphorus, Iron and Manganese Distribution in Sediment Cores of Six Wisconsin Lakes.

Limnol. Oceanogr. 19: 794-801.
Boyacioglu, E., 1972. Biophysical Analysis & Evaluation of Capability: Sturgeon Lake Area. Land Use Assignment Committee, Alberta Energy & Natural Resources, Edmonton.
Brewer, Peter G. and Joel C. Goldman, 1976. Alkalinity Changes Generated by Phytoplankton Growth. Limnol. Oceanogr. 21: 108-117.
Brezonik, Patrick L., 1972. Nitrogen: Sources and Transformations in Natural Waters. pg. 1-50 IN: Herbert E. Allen and James R. Kramer (eds.), Nutrients in Natural Waters. Wiley - Interscience, New York.
Brocke, L.K., 1977. The Canada Land Inventory Soil Capability for Agriculture in Alberta. Alberta Environment report, Edmonton.
Brown, Alison Leadley, 1971. Ecology of Fresh Water. Heinemann Educational Books, London.
Brown, E.S., 1955. Life in Fresh Water. Oxford University Press, London: Geoffrey Cumberlege.
Brutsaert, Wilfried and Gour-Tsyh Yeh, 1970. Implications of a type of Empirical Evaporation Formula for Lakes and Pans. Water Resources Research 6(4): 1202-1208.
Burt, John P. and Ralph E. Gentry, 1974. Water Quality Considerations in Planning Small Watersheds. JSWC 29(3): 133-135.
Canada Dept. of National Health & Welfare, 1969. Canadian drinking water standards and objectives, 1968. Queen's Printer, Ottawa.
Canadian Council on Rural Development, 1975. Tourism and Outdoor Recreation in Rural Development. Queen's Printer, Ottawa.
Carleton, T.J., 1972. Eutrophication of North American Lakes. Institute of Environmental Sciences and Engineering, University of Toronto, Publication No. ES-4.
Carlson, Reynold E., 1971. The Recreational Uses of Water. pg. 265-274 IN: E.J. Monke (ed.), Biological Effects in the Hydrological Cycle - Terrestrial Phase. Purdue University, Indiana.
Carr, N.G. and B.A. Whitton (eds.), 1973. The Biology of Blue-Green Algae. U. of Calif. Press, Berkeley.
Chapman, L.J. and D.M. Brown, 1966. The Climates of Canada for Agriculture. Dept. of Forestry & Rural Development, Queen's Printer, Ottawa.
Chiang, S.L. and G.W. Petersen, 1970. Soil Catena Concept for Hydrologic Interpretations. JSWC 25(6): 225-229.
Christiansen, Jerald E., 1966. Estimating Pan Evaporation and Evapotranspiration from Climatic Data. IN: Methods for Estimating Evapotranspiration. Irrigation and Drainage Specialty Conference, Las Vegas, Nevada, November 2-4, 1966.
Clegg, John, 1974. Freshwater Life. Wiley - Interscience, New York.
Clemens, Robert H., no date. The role of vegetation in shoreline management - A guide for Great Lakes shoreline property owners. Great Lakes Basin Commission, Fisheries & Environment Canada.
Cochrane, G. Ross and Earl J. Hajic, 1978. Landsat Mapping of Suspended Sediments in Lake Taupo, New Zealand. pg. 104-119 IN: Proc. for the 5th Canadian Symposium on Remote Sensing, Victoria, B.C., August 28-31, 1978.
Collins, A. Gene, 1973. Oil and Gas Wells - Potential Polluters of the Environment. pg. 66-76 IN: Fresh Water Pollution

I. Bacteriological and Chemical Pollutants. MSS Information Corp., New York.

Colman, E.A., 1953. Vegetation and Watershed Management. The Ronald Press Co., New York.

Cooke, G.W. and R.J.B. Williams, 1973. Significance of Man-Made Sources of Phosphorus - Fertilizers and Farming: The Phosphorus Involved in Agricultural Systems and Possiblities of its Movement into Natural Waters. Water Research 7(1-2): 19-33.

Cooley, James L., 1976. Nonpoint Pollution and Water Quality Monitoring. JSWC 31(2): 42-48.

Danielson, Mervin G., 1972. If You Want a Sediment-Free Lake. Soil Conservation 37(11): 251-252.

Davis, John C., 1975. Waterborne Dissolved Oxygen Requirements & Criteria with Particular Emphasis on the Canadian Environment. National Research Council of Canada, Assoc. Comm. on Scientific Criteria for Environmental Quality, Report No. 13.

Dean, E.T., 1968. Sturgeon Lake Control Structure, September 1968. Water Resources Division, Dept. of Agriculture, Edmonton.

Delfino, J.J., G.C. Bortleson and G.F. Lee, 1969. Distribution of Mn, Fe, P, Mg, K, Na & Ca in the Surface Sediments of Lake Mendota, Wisconsin. Environ. Sci. Technol. 3: 1189-1192.

Dillon, P.J., 1974. A Critical Review of Vollenweider's Nutrient Budget Model and Other Related Models. Water Resources Bulletin 10(5): 969-989.

Dillon, P.J., 1975. The Phosphorus Budget of Cameron Lake, Ontario: The Importance of Flushing Rate to the Degree of Eutrophy of Lakes. Limnol. Oceanogr. 20: 28-39.

Dillon, P.J. and F.H. Rigler, 1975. A Simple Method for Predicting the Capacity of a Lake for Development Based on Lake Trophic Status. J. of Fisheries Res. Brd. of Canada 32(9): 1519-1531.

Dotzenko, A.D., N.T. Papamichos and D.S. Romine, 1967. Effects of Recreational Use on Soil and Moisture Conditions in Rocky Mountain National Park. JSWC 22(5): 196-203.

Elder, John F., Richard H. Fuller and Alexander J. Horne, 1979. Physiochemical Factors & Their Effects on Algal Growth in a New Southern California Reservoir. Water Resources Bulletin 16(6): 1608-1617.

England, C.B., 1971. Extension of Hydrologic Process Modeling. pg. 240-247 IN: E.J. Monke (ed.), Biological Effects in the Terrestrial Phase. Purdue University, Indiana.

Environment Canada, 1978 & 1979. Surface Water Data - Alberta. Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa.

Environment Conservation Authority, 1976. Erosion of Land in North West Alberta. 5 volumes, Edmonton.

Ernst, D.E.W., 1977. Eutrophication of Inland Waters. pg. 63-98 IN: Frederick Coulston and Emil Mrak (eds.), Water Quality: Proceedings of an International Forum. Academic Press, London.

Erxleben, Jurgen Peter, 1972. Land Use - Snowmelt Runoff Relationships in the Whitemud Creek Basin. M. Sc. Thesis, Dept. of Geography, University of Alberta, Edmonton.

Etzel, James E., 1971. Pollution Control - Now and in the Future.

pg. 203-226 IN: E.J. Monke (ed.), Biological Effects in the Hydrological Cycle - Terrestrial Phase. Purdue University, Indiana.

Fast, Arlo W., 1973. Effect of Artificial Destratification on Primary Production & Zoobenthos of El Capitan Reservoir, California. Water Resources Research 9(3): 607-612.

Fast, A.W., Brian Moss and Robert Wetzel, 1973. Effects of Artificial Aeration on the Chemistry & Algae of Two Michigan Lakes. Water Resources Research 9(3): 624-632.

Fee, E.J., 1976. The Vertical & Seasonal Distribution of Chlorophyll in Lakes of the Experimental Lakes Area, N.W. Ont.: Implications for Primary Production Estimates. Limnol. Oceanogr. 21: 767-783.

Findley, Davis L., Diane I. Findley and Janet R. Stein, 1973. Surface Nitrogen & Plankton in Skaha Lake, B.C. Freshwater Biology 3(2): 111-122.

Fish, H., 1972a. The Natural Quality of Water Resources - I. Effluent and Water Treatment Journal 12(11): 585-594.

Fish, H., 1972b. The Natural Quality of Water Resources - 2: Water Pollution - Types, Causes and Effects. Effluent and Water Treatment Journal 12(12): 647-658.

Fisheries and Environment Canada, 1974, 1975, 1976, 1977, 1978 and 1979. The Canada Water Act Annual Report, Ottawa.

Fisheries and Environment Canada, 1977. Historical Streamflow Summary - Alberta - to 1976. Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa.

Fisheries and Environment Canada, 1977. Surface Water Quality in Canada - An Overview. Inland Waters Directorate, Ottawa.

Foehrenback, Jack, 1974. Eutrophication. J. Water Pollution Control Fed. 46(6): 1350-1355.

Foster, G.R., 1971. The Overland Flow Process Under Natural Conditions. pg. 173-185 IN: E.J. Monke (ed.), Biological Effects in the Hydrological Cycle - Terrestrial Phase. Purdue University, Indiana.

Found, W.C., A.R. Hill and E.S. Spence, 1974. Economic and Environmental Impacts of Land Drainage in Ontario. Geographical Monographs, No. 6, Canada.

Foyster, Angela M., 1973. Application of the Grid Square Technique to Mapping of Evapotranspiration. Journal of Hydrology 19: 205-226.

Fraga, G.W., 1967. An experiment in aerial surveillance of pollution indices at Lake Tahoe. Reprint from the Canadian Center for Remote Sensing.

Fraga, G.W., 1969. Aerial time lapse surveillance of pollution indices at Lake Tahoe. Reprint from the Canadian Center for Remote Sensing.

Frey, David G., 1966. Limnology in North America. The University of Wisconsin Press, Madison, Milwaukee and London.

Gächter, R., R.A. Vollenweider and W.A. Glooschenko, 1974. Seasonal Variations of Temperature & Nutrients in the Surface Waters of Lakes Ontario & Erie. J. of Fisheries Res. Brd. of Canada 31: 275-290.

Gasith, A. and A.D. Hasler, 1976. Airborne Litterfall as a Source of

Organic Matter in Lakes. Limnol. Oceanogr. 21: 253-258.
Gerloff G.E. and F. Skoog, 1954. Cell Contents of N and P as a Measure of Their Availability for Growth of Microcystis aeniginosa. Ecology 35: 348-353.
Gilat, Ch., H.I. Shuval, Y. Yoshpe-Purer and N. Cohen, 1969. The Use of Radioisotope Tracers in the Study of the Dispersion & Inactivation of Bacteria Discharged in Coastal Waters. pg. 269-288 IN: I. Shuvál (ed.), Developments in Water Quality Research.
Gladish, M., 1975. Shoreland Biophysical Field Surveys: Preliminary Results. Peace River Regional Planning Commission Sturgeon Lake Planning Study - Technical Working Paper No. 1.
Gladish, M., 1976. Technical Input for a Biophysical Survey of Sturgeon Lake & Some Calculations to Determine its Potential for Further Development. Peace River Regional Planning Commission Report.
Gladish, M., C. Mack and I. Wight, 1975. Sturgeon Lake Planning Study - Development Capacity Estimations and Engineering Alternatives. Peace River Planning Commission Technical Working Paper No. 2.
Glooschenko, Walter A., James E. Moore and Richard A. Vollenweider, 1974. Spatial and Temporal Distribution of Chlorophyll a and Pheopigments in Surface Waters of Lake Erie. J. Fisheries Res. Brd. of Canada 31: 265-274.
Glooschenko, Walter A., James E. Moore, Mohiuddin Munawar and R.A. Vollenweider, 1974. Primary Production in Lakes Ontario and Erie: A Comparative Study. J. Fisheries Res. Brd. of Canada 31: 253-263.
Golding, D.L. (ed.), 1974. Managing Forest Lands for Water: Proceedings of Research Management Seminar. Northern Forest Research Center Report NOR-X-13, Edmonton.
Goldman, Charles R., Robert C. Richards and Hans W. Paerl, 1974. Limnological Studies and Remote Sensing of the Upper Truckee River Sediment Plume in Lake Tahoe, California and Nevada. Remote Sensing of the Environment 3: 49-67.
Golterman, H.L., 1973. Natural Phosphate Sources in Relation to Phosphate Budgets: A Contribution to the Understanding of Eutrophication. Water Research 7(1-2): 3-17.
Golterman, H.L., 1975. Physical Limnology. Elsevier, Developments in Water Science 2.
Górski, Tadeusz and Jan Igor Rybak, 1974. Phosphorus Run-off From the Drainage Basin to Mikolajskie Lake. Ekologia Polska 22(2): 275-286.
Governments of Canada, Saskatchewan and Manitoba, 1972. Report of the Qu'Appelle Basin Study Board.
Gray, Donald M. (ed.), 1970. Handbook on the Principles of Hydrology. National Research Council of Canada, Water Information Center.
Greenlee, G.M., 1973. Soil Survey of Young's Point Prov. Park and Interpretation for Recreational Use. Soils Division, Alta. Institute of Pedology, Edmonton.
Groenwoud, H. van, 1977. Interim Recommendations for the Use of Buffer Strips for the Protection of Small Streams in the Maritimes. Maritimes Forest Research Centre, Info. Report M-X-74, Fredericton, N.B.
Grover, Nathan Clifford and Arthur William Harrington, 1943. Stream Flow Measurements, Records and Their Uses. John Wiley & Sons, Inc.,

New York.

Guy, Harold P. and George E. Ferguson, 1970. Stream Sediment: An Environmental Problem. JSWC 25(6): 217-222.

Hall, Warren A., 1971. Biological Hydrologic Systems. pg. 1-42 IN: E.J. Monke (ed.), Biological Effects in the Hydrological Cycle - Terrestrial Phase. Purdue University, Indiana.

Happey, C.M., 1970. The Effect of Stratification on Phytoplankton Diatoms in a Small Pond. Journal of Ecology 58: 635-651.

Hargrave, Barry T., 1972. Aerobic Decomposition of Sediment and Detritus as a Function of Particle Surface Area and Organic Content. Limnol. Oceanogr. 17: 583-596.

Harris, R. Cole and John Warkentin, 1974. Canada Before Confederation. Oxford University Press, Toronto.

Hickman, M., 1974. Effects of the discharge of thermal effluent from a power station on Lake Wabamun, Alberta, Canada - the epipelic and epipsammic algal communities. Hydrobiologia 45: 199-215.

Hickman, M., 1978. Ecological Studies on the Epipelic Algal Community in Five Prairie - Parkland Lakes in Central Alberta. Can. J. Bot. 56: 991-1000.

Hickman, M. 1979a. Phytoplankton of shallow lakes: Seasonal succession, standing crop and the chief determinants of primary productivity, 1. Cooking Lake, Alberta, Canada. Holarctic Ecology 1(4): 337-350.

Hickman, Michael, 1979b. Seasonal Succession, Standing Crop and Determinants of Primary Productivity of the Phytoplankton of Ministik Lake, Alberta, Canada. Hydrobiologia 64(2): 105-121.

Hickman, Michael, in press. Phosphorus, chlorophyll and eutrophic lakes. Arch. Hydrobiol.

Hickman, M. and D.M. Klarer, 1974. The growth of some epiphytic algae in a lake receiving thermal effluent. Arch. Hydrobiol. 74: 403-426.

Hickman, M. and D.M. Klarer, 1975. The effect of the discharge of thermal effluent from a power station on the primary productivity of an epiphytic algal community. Br. phycol. J. 10: 81-91.

Hickman, M. and C.G. Jenkerson, 1978. Phytoplankton Primary Productivity and Population Efficiency Studies in a Prairie Parkland Lake Near Edmonton, Alberta, Canada. Int. Revue ges. Hydrobiol. 63(1): 1-24.

Holecek, G., 1975. Sturgeon Lake - Hydrology Report: Summary of Results. Special Studies Section, Hydrology Branch, Alberta Environment, Edmonton.

Hollings, C.S. and M.A. Goldberg, 1971. Ecology and Planning. J. of the American Institute of Planners, July: 221-234.

Holme, N.A. and A.D. McIntyre, 1971. Methods for Study of Marine Benthos. International Biological Programme Handbook No. 16, Blackwell Scientific Publications, Oxford and Edinburgh.

Holm-Hansen, O., C.R. Goldman, R. Richards and P.M. Williams, 1976. Chemical and Biological Characteristics of a Water Column in Lake Tahoe. Limnol. Oceanogr. 21: 548-562.

Horstman, U., K.A. Ulbricht, and D. Schmidt, 1978. Detection of Eutrophication Processes from Air and Space. Proc. of the 12th International Symposium on Remote Sensing of the Environment

II: 1379-1389.
Hounam, C.E., 1973. Comparison Between Pan & Lake Evaporation. World Meteorological Organization, Technical Note No. 126, Geneva, Switzerland.
Huff, Dale D., 1971. Hydrologic Simulation and the Ecological System. pg. 23-46 IN: E.J. Monke (ed.), Biological Effects in the Hydrological Cycle - Terrestrial Phase. Purdue University, Indiana.
Hutchinson, Evelyn G., 1973. Eutrophication. American Scientist 61(3): 269-279.
International Joint Commission, Land Drainage Reference Group, 1974. Detailed Study to Assess Great Lakes Pollution from Land Use Activities. Reprint from the Canadian Center for Remote Sensing.
Jaakson, Reiner, Mario Des Buszynski and D. Botting, 1976. Carrying Capacity & Lake Recreation Planning. The Town Planning Review 47(4): 359-373.
Jackson, Togwell A. and David W. Schindler, 1975. The Biogeochemistry of Phosphorus in an Experimental Lake Environment: Evidence for the Formation of Humic-Metal-Phosphate Complexes. Verh. Internat. Verein. Limnol. 19: 211-221.
James, Danial W. and G. Fred Lee, 1974. A Model of Inorganic Carbon Limitation in Natural Waters. Water, Soil and Air Pollution 3: 315-320.
Jeglum, J.K., A.M. Boissonneau and V.F. Haavisto, 1974. Toward a Wetland Classification for Ontario. Great Lakes Forest Research Centre, Info. Rept. 0-X-215.
Jones, J.F., 1966. Geology & Groundwater Resources of the Peace River District, Northwestern Alberta. Research Council of Alberta, Bulletin 16.
Kakela, Peter John, 1969. Snow and the Thornthwaite Water Balance in a Subarctic Environment. Ph. D. Thesis, Dept. of Geography, University of Alberta, Edmonton.
Kalinin, G.P., 1974. Hydrological Basis for Forecasting & Calculating Runoff by Space Image of the Earth's Surface. Reprint from the Canadian Center for Remote Sensing.
Kappe, Stanley E., 1972. Listen! Phosphate Removal Isn't the Answer. Water & Wastes Engineering 9(4): 38-39,43.
Kemp, A.L.W., 1971. Organic Carbon & Nitrogen in the Surface Sediments of Lakes Ontario, Erie and Huron. J. Sed. Petrology 41: 537-548.
Klarer, David M. and Michael Hickman, 1975. The Effect of Thermal Effluent Upon the Standing Crop of an Epiphytic Community. Int. Revue ges. Hydrobiol. 60(1): 17-62.
Klashman, Lester M., Kenneth H. Walker and Richard T. Dewling, 1969. Pollution Control in the Raritan Bay Area. pg. 289-310 IN: I. Shuval (ed.), Developments in Water Quality Research.
Kleiber, P., P.H. Whitfield and W.E. Erlebach, 1978. Limitations of Single Water Samples in Representing Mean Water Quality: II. Spatial & Temporal Variation in Nutrient Concentrations in the Okanagan River at Oliver, B.C. Fisheries & Environment Canada, Technical Bulletin No. 107.
Klessig, Lowell L., 1976. Institutional Arrangements for Lake Management in Wisconsin. JSWC 31(4): 152-156.

Klock, Glen O., 1972. Snowmelt Temperature Influence on Infiltration and Soil Water Retention. JSWC 27(1): 12-14.

Koenings, Jeffery P. and Frank F. Hooper, no date. The Influence of Colloidal Organic Matter on Iron & Iron-Phosphorus Cycling in an Acid Bog Lake. Reprint of a report.

Kramer, James R., Stephen E. Herbes and Herbert E. Allen, 1972. Phosphorus: Analysis of Water, Biomass and Sediment. pg. 51-100 IN: Herbert E. Allen and James R. Kramer (eds.), Nutrients in Natural Waters. Wiley Interscience, New York.

Kunkle, Samuel H. and George H. Comer, 1971. Estimating Suspended Sediment Concentrations in Streams by Turbidity Measurements. JSWC 26(1): 18-20.

Lacate, D.S., 1969. Guidelines for Bio-Physical Land Classification. Subcommittee on Bio-physical Land Classification, Ottawa.

Lackie, T.H., 1966. Water Quality Criteria. Rural Water Supplies Symposium, Saskatoon, January 11-12, 1966.

Lacy, Charles H., 1969. Appraisal of the value of Sturgeon Lake to Waterfowl. Copy from Peace River Regional Planning Commission files.

Lance, J.C., 1972. Nitrogen Removal by Soil Mechanisms. J. Water Pollution Control Fed. 44: 1352-1361.

Laycock, A.H., 1958. Soil Surveying in Mountain Watersheds: The Problem & One Solution. AAG meeting paper, Santa Monica, California, August, 1958.

Laycock, A.H., 1968. The Water Balance of the Gull Lake Basin. Reprint from the Dept. of Geography, University of Alberta, Edmonton.

Laycock, A.H., 1967. Water Deficiency and Surplus Patterns in the Prairie Provinces. Prairie Provinces Water Board, No. 13, Regina.

Laycock, A.H., 1977. Water Resources Management in Alberta. paper presented at Annual Meeting of the Public Advisory Committees & the Environmental Conservation Authority, Red Deer.

Laycock, A.H., 1978. Precipitation Mapping in Alberta. pg. 133-149 IN: K.D. Hage and E.R. Reinelt (eds.), Essays on Meteorology and Climatology. The Dept. of Geography, University of Alberta, Edmonton.

Lean, D.R.S., 1973. Phosphorus Dynamics in Lake Water. Science 179(4074): 678-680.

Lester, W. Dale and James L. Carter Jr., 1972. Prevent Lake Pollution. Water & Wastes Engineering 9(3): 44-45.

Leven, Andrew A. and John A Williams, 1967. Hydrologic Soil Surveys for Wildland Watersheds. JSWC 22(6): 239-241.

Li, W.C., P.E. Armstrong, J.D. Williams, R.F. Harris and J.K. Syers, 1972. Rate & Extent of Inorganic Phosphate Exchange in Lake Sediments. Soil Sci. Soc. Amer. Proc. 36: 279-285.

Likens, Gene E., 1973. Primary Production: Freshwater Ecosystems. Human Ecology 1(4): 347-356.

Lillesand, Thomas M., Frank L. Scarpace and James L. Clapp, 1975. Water Quality in Mixing Zones. Photogrammetric Engineering & Remote Sensing XLI(3): 285-298.

Lindsey, Alton A., 1971. The Need for Nature Preserves. pg. 259-264

IN: E.J. Monke (ed.), Biological Effects in the Hydrological Cycle - Terrestrial Phase. Purdue University, Indiana.

Loehr, Raymond C., 1974. Characteristics & Comparative Magnitude of Non-Point Sources. J. of Water Pollution Control Fed. 46(8): 1849-1872.

Loftis, Jim C. and Robert C. Ward, 1978. Statistical Tradeoffs in Monitoring Network Design. AWRA Symposium for Establishment of Water Quality Monitoring Programs.

Longley, Richmond W., 1972. The Climate of the Prairie Provinces. Environment Canada Climatological Studies, No. 13, Toronto.

Lukens, J.E., 1968. Color aerial photography for aquatic vegetation surveys. Reprint from the Canadian Center for Remote Sensing.

Lund, J.W.E., 1950. Studies on Asteriorella formosa Hass. II Nutrient depletion and the spring maximum. Journal of Ecology 38: 1-35.

MacGregor, James G., 1972. A History of Alberta. Hurtig Publishers, Edmonton.

MacKintosh, W.A., 1934. Canadian Frontiers of Settlement - Vol 1: Prairie Settlement. MacMillan Co. of Canada Ltd., Toronto.

Malila, W.A. and T.W. Wagner, 1974. Multispectral Remote Sensing of Elements of Water & Radiation Balances. 8th International Symposium on Remote Sensing of the Environment 1: 639-647.

Manning, Robert E., no date. Impacts of Recreation on Riparian Soils and Vegetation. Reprint of a report.

Martz, Lawrence W., 1979. Sediment Yield of Spring Creek Watershed, Alberta. M. Sc. Thesis, Dept. of Geography, University of Alberta, Edmonton.

Mather, John R., 1974. Climatology: Fundamentals & Applications. McGraw-Hill Book Co. Series in Geography.

McDonald, Dennis G., 1973. The Effects of Seismic Explosions on Fish in Sturgeon Lake, Alberta. Fish & Wildlife Division, Alta. Dept. of Lands & Forests, Edmonton.

McGuinness, J.L., L.L. Harrold and W.M. Edwards, 1971. Relation of Rainfall Energy Streamflow to Sediment Yield from Small & Large Watersheds. JSWC 26(6): 233-235.

McGuinness, J.L. and William A. Edwards, 1975. A Watershed Soils Index of Runoff Potential. JSWC 30(4): 184-186.

McKay, G.A., 1962. Evaporation from Weyburn Reservoir. Canada Dept. of Agr., PFRA Progress Report, 1960-1961.

McLay, C.L., 1973. Wind-Blown Dust as a Source of Nutrients for Aquatic Plants. Environmental Pollution 5(3): 173-180.

McNeely, R.N. (ed.), 1979. Water Quality Interpretive Report, Ontario, 1967-1977. Inland Waters Directorate, Ottawa.

McNeely, R.N., V.P. Neimanis and L. Dwyer, 1979. Water Quality Sourcebooks: A Guide to Water Quality Parameters. Inland Waters Directorate, Ottawa.

McNeil, W.R., K.P.B. Thomson and J. Jerome, 1976. The Application of Remote Spectral Measurements to Water Quality Monitoring. Canadian Journal of Remote Sensing 2(1): 48-58.

Mechalas, Byron J., Kenneth K. Hekimian, Lewis A. Schinaze and Ralph H. Dudley, 1972. Water Quality Criteria Data Book - Vol. 4 - An Investigation into Recreational Water Quality.

Water Pollution Control Research Series, U.S. Env'tl. Protection Agency, Wash., D.C.

Meiman, J.R. and S.H. Kunkle, 1967. Land Treatment & Water Quality Control. JSWC 22(2): 67-70.

Meloche, V.W., G. Leader, L. Safrinski and C. Juday, 1938. The silica and diatom content of Lake Mendota water. Trans. Wisc. Acad. Sci. Arts Lett. 31: 363-371.

Meyer, L.D. and J.V. Mannering, 1971. The Influence of Vegetation and Vegetative Mulches on Soil Erosion. pg. 355-366 IN: E.J. Monke (ed.), Biological Effects in the Hydrological Cycle - Terrestrial Phase. Purdue University, Indiana.

Mitchell, Patricia, 1979a. Skeleton, Garner, Muriel Lakes - Water Quality Studies. Water Quality Control Branch, Pollution Control Division, Alberta Environment, Edmonton.

Mitchell, Patricia, 1979b. Trophic Status of Sandy and Nakamun Lakes. Water Quality Control Branch, Pollution Control Division, Alberta Environment, Edmonton.

Moore, Gerald K., 1978. Satellite Surveillance of Physical Water Quality Characteristics. Proc. of the 12th International Symposium on Remote Sensing of the Environment 1: 445-462.

Mortimer, C.H., 1974. Lake Hydrodynamics. Center for Great Lakes Studies, Report No. 109, University of Wisconsin, Milwaukee.

Moss, B., 1967a. A spectrophotometric method for the estimation of percentage degradation of chlorophylls to pheo-pigments in extracts of algae. Limnol. Oceanogr. 12: 335-340.

Moss, B., 1967b. A note on the estimation of chlorophyll a in freshwater algal communities. Limnol. Oceanogr. 12: 340-342.

Moss, B., 1970. Seston Composition in 2 Freshwater Pools. Limnol. Oceanogr. 15: 504-513.

Moss, E.H., 1955. The Vegetation of Alberta. The Botanical Review 21(9): 493-567.

Munday, J.C., 1974. Water Quality of Lakes of S. Ont. from Erts-1. pg. 78-85 IN: Proc. of the 2nd Canadian Symposium on Remote Sensing.

Munson, W.C., 1966. Estimating Consumptive Use by the Munson P.E. - Index Method. pg. 65-107 IN: ASCE, Methods for Estimating Evapotranspiration. November 2-6, 1966, Las Vegas.

Mustonen, S.E., 1976. Water Balance Transformation of Meliorated Areas. pg. 53-59 IN: Man-Made Transformations of Meliorated Areas. Proc. of the Symposium of the International Geographical Union, July 19-26, 1976, Leningrad, U.S.S.R.

Nicholaichuk, W., 1967. Comparative Watershed Studies in Southern Saskatchewan. ASAE Transactions 10: 502-504.

North, Margaret E.A., 1976. A Plant Geography of Alberta. Dept. of Geography Monograph Series, University of Alberta, Edmonton.

Odum, Eugene P., 1971. Fundamentals of Ecology. W.B. Saunders Company, Toronto.

Odynsky, Wm., A. Wynnyk and J.D. Newton, 1956. Soil Survey of the Grande Prairie and Sturgeon Lake Sheets. Dept. of Extension, University of Alberta, Edmonton.

Ojamaa, Peter M., 1978. Biophysical Analysis and Evaluation of Capability: Little Smoky Area. Resource Evaluation Branch,

Alberta Energy & Natural Resources, Edmonton.

Osborne, P.L. and Brian Moss, 1977. Paleolimnology & trends in the P & Fe Budgets of an Old Man-made Lake, Barton Broad, Norfolk. Freshwater Biology 7: 213-233.

Overton, D.E., 1971. Mechanics of Surface Runoff on Hillslopes. pg. 186-210 IN: E.J. Monke (ed.), Biological Effects in the Hydrological Cycle - Terrestrial Phase. Purdue University, Indiana.

Parker, J. Harold, 1972. How Fertilizer Moves & Reacts in the Soil. Crops & Soils Magazine 25(2): 7-11.

Parkes, J.G.M., 1973. Public Perceptions of Water Quality & Their Effect on Water-Based Recreation. Environment Canada - Social Science Series No. 8, Ottawa.

Peace River Regional Planning Commission, 1974. Local & Site Factors Pertinent to an Evaluation of the Sturgeon Lake Recreational Housing Development Proposal. Reprint of a discussion paper.

Pearsall, W.H., 1923. A theory of diatom periodicity. Journal of Ecology 11: 165-183.

Penman, H.L., 1963. Vegetation & Hydrology. Technical Communication #53, Commonwealth Bureau of Soils, Harpenden, England.

Pereira, H.C., 1973. Land Use & Water Resources in Temperate & Tropical Climates. Cambridge University Press, New York.

Persinger, Ival D. and Joseph E. Yahner, 1970. Relation of Percolation Rates to Soil Texture on Several Indiana Soils. JSWC 25(5): 189-193.

Peters, Roger H., 1973. Nutrient Balances for the Evaluation of Nutrient Sources in Water Quality Management. Water Resources Bulletin 9(1): 49-53.

Pierce, Robert S., C. Wayne Martin, Calvin C. Reeves, Gene E. Likens and F. Herbert Bormann, no date. Nutrient Loss From Clear-cuttings in New Hampshire. pg. 285-294 IN: National Symposium on Watersheds in Transition.

Powell, J.M. and D.C. MacIver, 1977. A Summer Climate Classification for the Forested Area of the Prairie Provinces using Factor Analysis. Northern Forest Research Center Info. Report NOR-X-177, Edmonton.

Quaternary Geosciences Ltd., 1973. Geologic & Hydrologic Report on Young's Point Provincial Park. Reprint of a report for Alberta Parks Planning, Edmonton.

Rawson, D.S., 1951. The Total Mineral Content of Lake Waters. Ecology 32: 669-672.

Rawson, D.S., 1952. Mean Depth & the Fish Production of Large Lakes. Ecology 33: 513-521.

Rawson, D.S., 1953. The Standing Crop of Net Plankton in Lakes. J. Fisheries Res. Brd. of Canada 10: 224-237.

Rawson, D.S., 1956. Algal Indicators of Trophic Lake Types. Limnol. Oceanogr. 1: 18-25.

Rawson, D.S., 1960. A Limnological Comparison of 12 Large Lakes in Northern Saskatchewan. Limnol. Oceanogr. 5: 195-211.

Reeves, Robert G., Abraham Anson and David Landen (eds.), 1975. Manual of Remote Sensing. American Society of Photogrammetry, Virginia.

Reckhow, Kenneth H., 1978a. Lake Phosphorus Budget Sampling Design.

American Water Resources Assoc. Sym. on the Establishment of Water Quality Monitoring Programs.

Reckhow, Kenneth H., 1978b. Lake Quality Discriminant Analysis. Water Resources Bulletin 14(4): 856-867.

Ritchie, Jerry C., 1972. Sediment, Fish & Fish Habitat. JSWC 27(3): 124-128.

Robertson, J.A. and J.B. McQuitty, 1978. Feedlot Pollution in Central Alberta. Agriculture & Forestry Bulletin, Dept. of Extension, University of Alberta.

Robinove, C.J., 1966. A preliminary evaluation of airborne & space-borne remote sensing data for hydrologic uses. Reprint from the Canadian Center for Remote Sensing.

Rogers, Robert H., Larry E. Reed and V. Elliott Smith, 1975. Computer Mapping of turbidity & circulation patterns in Saginaw Bay, Michigan (Lake Huron) from ERTS Data. pg. 415-429 IN: Proc. of the American Society of Photogrammetry, 41st annual meeting Mar. 9-14, 1975, Washington, D.C.

Römkens, M.J.M., D.W. Nelson and C.B. Roth, 1975. Soil Erosion on Selected High Clay Subsoils. JSWC 30(4): 173-176.

Rowe, J.S., 1972. Forest Regions of Canada. Dept. of Environment, Canadian Forestry Service, Publication No. 1300.

Ruttner, Franz, 1975. Fundamentals of Limnology. University of Toronto Press, Toronto.

Round, F.E., 1964. The Ecology of Benthic Algae. IN: Daniel F. Jackson (ed.), Algae and Man. Plenum Press, New York.

Round, F.E., 1973. The Biology of the Algae. Edward Arnold (Publishers) Ltd., London.

Sager, Paul E. and James H. Wiersma, 1975. Phosphorus Sources for Lower Green Bay, Lake Michigan. J. of the Water Pollution Control Fed. 47(3): 504-514.

Salánki, J. and J.E. Ponyi(eds.), 1975. Limnology of Shallow Waters. Symposium Biologica Hungarica 15, Akademiai Kiado, Budapest.

Sargent, Frederick O. and William H. Bingham, 1969. Lakeshore Land Use Controls. Vermont Agr. Experiment Station, University of Vermont, Research Report MP57.

Satterlund, Donald R., 1972. Wildland Watershed Management. Washington State University, The Ronald Press Co., New York.

Schelske, Claire L., no date. Silica & Nitrate Depletion as Related to Rate of Eutrophication in Lake Michigan, Lake Huron & Lake Superior. University of Michigan M. Sc. Thesis, Ann Arbor, Michigan.

Schelske, Claire L., 1971. Nutrient Inputs & Their Relationship to Accelerated Eutrophication in Lake Michigan. pg. 68-86 IN: E.J. Monke (ed.), Biological Effects in the Hydrological Cycle - Terrestrial Phase, Purdue University, Indiana.

Scherz, James P. and John F. Domelen, 1973. Aircraft & Satellite Monitoring of Lake Superior Pollution Sources. 2nd Environmental Quality Sensor's Conference, October 10-11, 1973, Las Vegas, Nevada.

Schindler, D.W., 1974. Eutrophication & Recovery in Experimental Lakes: Implications for Lake Management. Science 184: 897-899.

Schindler, D.W. and D.R.S. Lean, 1974. Biological and Chemical Mechanisms in Eutrophication of Freshwater Lakes. Annals of the

New York Academy of Sciences 250: 129-135.

Schindler, D.W., D.R.S. Lean and E.J. Fee, 1972. Nutrient Cycling in Freshwater Ecosystems. reprinted from Proc. of a Symposium on Productivity of World Ecosystems.

Schroeder, D.G., 1974. Goose Creek Survey, 1974. Fish & Wildlife Division, Dept. of Recreation, Parks & Wildlife, Edmonton.

Schroeder, D.G. and D.T. Walty, 1977. Goose Creek Survey, 1977. Fish & Wildlife Division, Dept. of Recreation, Parks & Wildlife, Edmonton.

Schwabe, Gerhard H., 1974. The Lake as Ecosystem. Universitas 16(3): 213-226.

Schwabe, G.H., L. Frevert and J.T. Barnes, 1952. Manual of Soil & Water Conservation Engineering. Wm. C. Brown & Co. (Pub.), Dubuque, Iowa.

Scorgie, D.A. and W.M. Wilson, 1973. Phosphorous Concentrations as a factor in the Eutrophication of Lake Ontario. Report of Canada Centre for Inland Waters, Burlington.

Serruya, C. and T. Berman, 1970. The Evolution of Nitrogen Compounds in Lake Kinneret. pg. 73-78 IN: I. Shuval (ed.), Developments in Water Quality Research.

Shapiro, Joseph, 1973. Blue-Green Algae: Why They Become Dominant. Science 179: 382-384.

Shaw, W.G.A., 1974. Interim Lake Report & Lake Philosophy Statement. Red Deer Regional Planning Commission report.

Sheffield, C.W. and R.T. Kaleel, 1970. Effects of Agricultural Discharges into Freshwater Lakes. pg. 904-913 IN: Purdue University Engineering Extension Series No. 137, Indiana.

Shelef, G. and R. Halperin, 1969. Wastewater nutrients & algae growth potential. pg. 211-228 IN: I. Shuval (ed.), Developments in Water Quality Research.

Shiau, S.Y. and K.S. Davar, 1973. Modified Penman Method for Potential E.T. from Forest Regions. Journal of Hydrology 18: 349-365.

Singh, T. and Y.P. Kalra, 1975. Specific Conductance method for in situ estimation of total dissolved solids. J. Am. Water Works Assoc. 67: 99-100.

Singh, Teja, 1976. Yields of Dissolved Solids from Aspen-Grassland & Spruce-Fir Watersheds in Southwestern Alberta. Journal of Range Management 29(5): 401-405.

Singh, Teja and Graham R. Hillman, 1972. Reconnaissance Survey of Infiltration & Related Hydrological Problems in Northern Alta. & the adjacent N.W.T. Northern Forest Research Center Info. Report NOR-X-29.

Singh, Teja and Y.P. Kalra, 1977. Estimation of Natural Pollution Loads from Streamflow Measurements in Remote Catchments. Water, Air & Soil Pollution 7: 111-116.

Slaymaker, O. and L.M. Lavkulich, 1978. A Review of Land Use - Water Quality Interrelationships & a Proposed Method for Their Study. Westwater Research Center, Technical Report No. 13, UBC, Vancouver.

Smith, Andrée and J.D. Addington, 1978. Water Quality Monitoring of Lake Mead: A Practical Look at the Difficulties Encountered in the Application of Remotely Sensed Data to Analysis of Temporal Change. pg. 174-186 IN: the 5th Canadian Symposium on Remote Sensing,

August 28-31, 1978, Victoria, B.C.

Snyder, W.M. and W.G. Knisel Jr., 1974. Why Should We Predict Runoff for Ungaged Drainage Areas. JSWC 29(5): 229-231.

Sontheimer, Heinrich and Wolfgang Kuhn, 1977. Parameters for Water Assessment. pg. 51-56 IN: Frederick Coulston and Emil Mrak (eds.), Water Quality: Proceedings of an International Forum. Academic Press, London.

Stark, N., 1972. Nutrient Cycling Pathways & Litter Fungi. Bioscience 22(6): 355-360.

State Lakes Preservation Committee, 1977. A plan for the Classification, Preservation & Restoration of Lakes in Northeastern South Dakota. State of South Dakota and the Old West Regional Commission.

Stern, Helman I., 1973. A Model for Population - Recreational Quality Interactions of a Fresh Water Site. Socio-Econ. Plan. Sci. 7: 1-11.

Stone, Larry J., 1974. A Study: Effects of Geology & Nutrients on Water Quality Development. J. of American Water Works Assoc. 66(8): 489-494.

Strickland, J.D.H. and T.R. Parsons, 1972. A Practical Handbook of Seawater Analysis. Fish. Res. Bd. Can., Bulletin 167, 2nd edition.

Strong, A.E., 1972. Detection of Circulation Features in the Great Lakes. Reprint from the Canadian Center for Remote Sensing.

Sutcliffe, W.H. Jr., 1972. Some Relations of Land Drainage, Nutrients, Particulate Material & Fish Catch in Two Eastern Canadian Bays. J. of the Fisheries Res. Brd. of Canada 29(4): 357-362.

Svatkova, T.G., 1974. Hydrographic interpretation of photographs from space. Reprint from the Canadian Center for Remote Sensing.

Swenson, H.A. and H.L. Baldwin, 1965. A Primer on Water Quality. U.S. Gov't. Printing Office, Wash., D.C.

Tenny, Mark W. and T.E. Higgins, 1972. Effects on Surface Waters. J. Water Pollution Control Fed. 44(6): 1204-1208.

Thornthwaite, C.W., 1948. An Approach Toward a Rational Classification of Climate. Geographical Review 38(1): 55-94.

Thornthwaite, C.W. and J.R. Mather, 1957. Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. Publication in Climatology 10(3): 185-311.

Timmons, D.R., R.F. Holt and J.J. Latterell, 1970. Leaching of Crop Residues as a Source of Nutrients in Surface Runoff Water. Water Resources Research 6(5): 1367-1375.

Torrey, M.S. and G.F. Lee, 1976. Nitrogen Fixation in Lake Mendota, Madison, Wisconsin. Limnol. Oceanogr. 21: 365-378.

Tovell, Walter M., 1977. Not Ours to Control - Living with Changing Lake Levels. Rotunda 10(3).

Traversy, W.J. and M. Comba, 1971. Phosphates & the Canada Water Act. Dept. of Environment, Technical Bulletin No. 48, Ottawa.

Tretiak, L., 1976. Sturgeon Lake Bird Survey, May - August, 1976. Reprint from Peace River Regional Planning Commission files.

Trew, David O., David J. Belleveau and Eva I. Yonge, 1978. Baptiste Lake Study - Summary Report. Water Quality Control Branch, Alberta Environment, Edmonton.

United States, Dept. of Health, Education and Welfare, 1962. Public Health Service Drinking Water Standards - 1962. Government Printing Office, Wash., D.C.

United States, Dept. of the Interior, 1967. Water Measurement Manual. Bureau of Reclamation, Government Printing Office, Wash., D.C.

United States, Dept. of the Interior, 1968. Surface Water Criteria for Public Water Supplies. IN: Report of the Committee on Water Quality Criteria. Federal Water Pollution Control Administration, Government Printing Office, Wash., D.C.

Turner, Nolan, 1973. Young's Point Provincial Park Development Report. Parks Division, Alberta Lands & Forests, Edmonton.

Vallentyne, John R., 1974. The Algal Bowl - Lakes and Man. Environment Canada, Fisheries & Marine Service Miscellaneous Special Publication 22, Ottawa.

Vanderholm, Dale H. and Robert C. Ward, 1973. Data Acquisition for Water Quality Management - An Analysis of Traditional Grab Sampling Methods. pg. 107-112 IN: National Symposium on Watersheds in Transition.

Van Deusen, R.D., 1973. Swans Control Plants. American Fish Farmer & World Aquaculture News.

Vollenweider, R.A. and P.J. Dillon, 1974. The Application of the Phosphorus Loading Concept to Eutrophication Research. Canada Centre for Inland Waters, Burlington, Ont., NRCC Report No. 13690.

Wagemann, R. and B. Graham, 1973. Membrane & Glass Fibre Filter Contamination in Chemical Analysis of Fresh Water. Water Research 8: 407-412.

Wallis, P.M., 1979. Sources, Transportation & Utilization of Dissolved Organic Matter in Groundwater & Streams. Scientific Series No. 100, Inland Waters Directorate, Ottawa.

Ward, R.C., 1967. Principles of Hydrology. McGraw-Hill Book Co. Ltd., London.

Warry, N.D., 1978a. Chemical Limnology of the North Channel, 1974. Scientific Series No. 92, Inland Waters Directorate, Burlington, Ont.

Warry, N.D., 1978b. Chemical Limnology of Georgian Bay, 1974. Fisheries & Environment Canada, Scientific Series No. 91, Ottawa.

Wellmon, Bernard Brian, 1965. A History of the Peace River Country of Western Canada. M.A. Thesis, History Department, University of Alberta.

Wetzel, Robert G., 1975. Limnology. W.B. Saunders Company, Toronto.

Wezernak, C.T. and F.C. Polcyn, 1972. Eutrophication Assessment using Remote Sensing Techniques. 8th International Symposium on Remote Sensing of the Environment, October 2-6, 1972.

Wiedeman, Varley E., 1970. Economic Aspects of Algae. IN: R. Weist and W. Greeson (eds.), Hydrobiology. Proc. of an Amer. Water Res. Assoc. Symposium.

Wight, Ian and Charles Mack, 1975. Sturgeon Lake Planning Study - Interim & Progress Report. Peace River Regional Planning Commission.

Wight, J.B., 1973. Aspects of Evaporation and Evapotranspiration in the Water Balance of Baker Creek Basin, Near Yellowknife, Northwest Territories. M. Sc. Thesis, Dept. of Geography, University of Alberta, Edmonton.

Williams, A.R. and R.P.C. Morgan, 1976. Geomorphological Mapping Applied to Soil Erosion Evaluation. JSWC 31(4): 164-168.

World Health Organization, 1958 and 1971. International Standards for Drinking Water. Geneva.

World Health Organization, 1961. European Standards for Drinking Water. Geneva.

Yasuoka, Y., Y. Iikura and T. Miyazaki, 1978. Quantitative Description and Analysis of Remotely Sensed Water Quality Distribution. Proc. 12th International Symposium on Remote Sensing of the Environment II: 1309-1318.

Yeske, L., F. Scarpace, and T. Green, 1975. Measurement of lake currents. Photogrammetric Engineering 41(5): 637-646.

Zoltai, S.C., 1976. Wetland Classification. Proc. 1st Meeting Can. Comm. on Ecological (Bio-physical) Land Class., May 25-28, 1976, Petawawa, Ont.

Zoltai, S.C., F.C. Pollett, J.K. Jeglum and G.D. Adams, 1973. Developing a Wetland Classification for Canada. pg. 497-511 Proc. of the 4th North American Forest Soils Conference, Laval University, Quebec.

Zuzel, John F., David C. Robertson and Walter J. Rawls, 1975. Optimizing Long Term Streamflow Forecasts. JSWC 30(2): 76-79.

APPENDIX 1

CLIMATIC RECORDS

10 YEAR AND NORMAL MONTHLY PRECIPITATION RECORD
FOR GRANDE PRAIRIE, ALBERTA (in mm)

YEARS OF COVERAGE	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YR
1941-70	34.0	28.2	21.3	21.6	37.6	64.5	60.5	52.6	34.3	24.9	31.0	30.5	442.0
1969-78	30.5	18.1	21.0	17.3	27.0	66.0	63.4	60.2	50.3	20.4	29.8	29.0	432.8
1978	15.4	3.1	14.0	26.1	13.4	57.3	42.1	55.3	63.3	8.8	14.5	19.4	332.7
1977	29.7	3.8	9.5	6.4	93.4	30.2	144.7	51.7	23.1	31.6	11.6	20.8	456.5
1976	21.4	19.0	16.6	17.0	47.9	104.0	52.3	155.0	35.4	12.7	6.6	47.3	535.2
1975	23.6	15.2	18.8	17.5	22.1	56.4	30.0	54.1	9.4	40.9	52.3	52.6	392.9
1974	74.9	19.8	50.6	15.0	50.3	14.5	68.8	38.4	64.5	16.8	23.1	23.9	460.6
1973	16.8	27.7	2.5	17.8	8.9	67.8	26.7	73.7	39.1	34.3	37.3	26.4	379.0
1972	28.5	59.9	28.2	7.6	1.0	82.8	96.5	44.7	51.3	35.3	42.2	34.0	512.0
1971	61.7	5.6	15.0	16.3	3.1	169.7	98.6	64.0	71.9	3.8	30.7	34.3	574.7
1970	13.7	10.9	27.4	10.7	20.8	29.2	37.1	14.0	21.3	8.4	39.4	22.4	255.3
1969	19.4	15.5	27.4	38.4	9.1	47.8	36.8	51.1	123.4	11.2	40.1	9.1	429.3

source: Atmospheric Environment Service,
1978 & 1975

10 YEAR AND NORMAL MONTHLY TEMPERATURE RECORD
FOR GRANDE PRAIRIE, ALBERTA (in °C)

YEARS OF COVERAGE	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YR
1941-70	-17.3	-12.4	-7.4	2.4	10.0	13.7	16.0	14.8	10.2	4.2	-6.3	-13.2	1.2
1969-78	-18.0	-11.6	-6.4	3.5	10.4	14.0	15.6	14.4	9.4	4.1	-6.9	-13.9	1.2
1978	-17.3	-11.0	-3.0	4.5	9.0	15.4	16.5	14.1	9.5	6.9	-7.1	-11.0	2.2
1977	-11.4	-2.0	-4.2	6.5	10.0	14.1	14.6	13.6	9.5	3.8	-7.1	-20.0	2.3
1976	-11.5	-11.5	-6.5	5.3	10.9	11.9	14.9	15.1	12.1	4.6	-1.2	-10.6	2.8
1975	-12.2	-16.3	-8.7	0.6	9.7	13.4	17.7	12.7	11.5	3.7	-7.6	-12.0	1.0
1974	-21.2	-11.0	-11.4	2.9	8.4	14.1	14.1	13.8	9.2	5.9	-3.8	-7.9	1.1
1973	-13.8	-12.1	-4.2	3.8	11.4	12.9	15.4	13.3	9.6	3.3	-15.6	-13.6	0.9
1972	-20.3	-18.3	-7.1	-0.1	11.7	14.3	14.3	15.4	5.9	2.3	-6.4	-17.9	-0.5
1971	-21.3	-10.2	-8.0	3.7	12.2	14.4	16.6	16.4	8.3	3.3	-6.1	-17.3	1.0
1970	-19.0	-6.6	-3.6	4.3	9.5	15.3	16.4	16.0	9.3	4.2	-10.4	-18.8	1.4
1969	-31.8	-16.6	-7.4	3.9	10.7	14.3	15.4	13.8	8.6	2.7	-4.1	-9.6	0.0

source: Atmospheric Environment Service, 1978 & 1975

APPENDIX 2

TABULATED WATER BALANCE RESULTS

GRANDE PRAIRIE WATER BALANCE SUMMARY[1] - 50 mm Storage

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.[2]
1969	429.3	510.8	211.8	83.9	+46.3	299.0	616.7
1970	255.3	528.1	336.6	95.8	-32.0	191.5	696.4
1971	574.7	527.7	69.5	107.7	+8.7	458.2	562.5
1972	512.0	479.6	146.8	144.7	+34.4	332.8	553.0
1973	379.0	502.8	199.5	101.9	-26.2	303.3	602.6
1974	460.6	491.8	173.6	174.0	-31.7	318.2	578.6
1975	392.9	494.8	247.3	68.7	+76.7	247.5	618.5
1976	535.2	536.4	62.1	130.7	-69.8	474.3	567.5
1977	456.5	510.8	89.3	46.9	-12.0	421.5	555.5
1978	332.7	526.1	209.7	24.4	-8.0	316.4	631.0
average	432.8	510.9	174.6	97.9	-1.4	336.3	598.2

1. calculated according to Thornthwaite's procedures as published in 1957 using data from the Atmospheric Environment Service, 1978.
2. calculated according to equation: L.E. = P.E. + ½D

WITH 18% PRECIPITATION CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	506.4	510.8	185.8	136.7	+44.6	325.0	603.7
1970	301.2	528.1	311.2	116.0	-31.7	216.9	683.7
1971	678.0	527.7	46.5	164.1	+32.6	481.2	551.0
1972	604.2	479.6	106.3	202.1	+28.7	373.3	532.8
1973	447.0	502.8	157.7	139.7	-37.8	345.1	581.7
1974	543.6	491.8	128.1	217.9	-38.1	363.7	555.9
1975	463.7	494.8	216.3	93.9	+91.7	278.5	603.0
1976	631.6	536.4	19.7	195.2	-80.3	516.7	546.3
1977	538.6	510.8	36.1	80.1	-16.3	474.7	528.9
1978	392.7	526.1	161.7	41.8	-13.4	364.4	607.0
average	510.7	510.9	136.9	138.8	-2.0	374.0	579.4

WITH 15% RAIN AND 50% SNOW CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	544.8	510.8	188.8	180.8	+41.9	322.0	605.2
1970	334.4	528.1	311.8	145.7	-27.6	216.3	684.0
1971	709.4	527.7	44.2	202.7	+23.1	483.5	549.8
1972	666.3	479.6	113.0	250.5	+49.1	366.6	536.1
1973	487.2	502.8	155.7	185.4	-45.3	347.1	580.7
1974	612.0	491.8	128.8	287.0	-38.1	363.0	556.2
1975	508.2	494.8	221.5	136.7	+97.2	273.3	605.6
1976	651.3	536.4	26.0	235.1	-94.2	510.4	549.4
1977	551.0	510.8	41.6	101.7	-20.0	469.2	531.6
1978	404.1	526.1	168.5	62.6	-15.9	357.6	610.4
average	546.9	510.9	140.0	178.8	-3.0	370.9	580.9

GRANDE PRAIRIE WATER BALANCE SUMMARY - 100 mm Storage

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	429.3	510.8	161.8	14.6	+65.6	349.0	591.7
1970	255.3	528.1	286.6	65.1	-51.3	241.5	671.4
1971	574.7	527.7	5.9	44.1	+8.7	521.8	530.7
1972	512.0	479.6	96.8	94.7	+34.4	382.8	528.0
1973	379.0	502.8	149.5	51.9	-26.2	353.3	577.6
1974	460.6	491.8	123.6	124.0	-31.7	368.2	553.6
1975	392.9	494.8	197.3	18.7	+76.7	297.5	593.5
1976	535.2	536.4	12.1	80.7	-69.8	524.3	542.5
1977	456.5	510.8	42.4	0	-12.0	468.4	532.0
1978	332.7	526.1	185.3	0	-8.0	340.8	618.8
average	432.8	510.9	126.1	49.4	-1.4	384.8	574.0

WITH 18% PRECIPITATION CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	506.4	510.8	135.8	45.2	+86.1	375.0	578.7
1970	301.2	528.1	261.2	107.5	-73.2	266.9	658.7
1971	678.0	527.0	0	70.0	+80.2	527.7	527.7
1972	604.2	479.6	56.3	199.7	-18.9	423.3	507.8
1973	447.0	502.8	107.7	89.7	-37.8	395.1	556.7
1974	543.6	491.8	78.1	167.9	-38.1	413.7	530.9
1975	463.7	494.8	166.3	43.4	+91.7	328.5	578.0
1976	631.6	536.4	0	117.3	-22.1	536.4	536.4
1977	538.6	510.8	0	78.6	-50.9	510.8	510.8
1978	392.7	526.1	111.7	15.4	-37.0	414.4	582.0
average	510.7	510.9	91.7	93.5	-2.0	419.2	556.8

WITH 15% RAIN AND 50% SNOW CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	544.8	510.8	138.8	91.6	+81.1	372.0	580.2
1970	334.4	528.1	261.8	134.9	-66.8	266.3	659.0
1971	709.4	527.7	0	113.6	+68.0	527.7	527.7
1972	666.3	479.6	63.0	245.4	+4.2	416.6	511.1
1973	487.2	502.8	105.7	135.4	-45.3	397.1	555.7
1974	612.0	491.8	78.8	237.0	-38.1	413.0	531.2
1975	508.2	494.8	171.5	86.7	+97.2	323.3	580.6
1976	651.3	536.4	0	161.8	-46.9	536.4	536.4
1977	551.0	510.8	0	93.6	-53.5	510.8	510.8
1978	404.1	526.1	118.5	26.4	-29.7	407.6	585.4
average	546.9	510.9	93.8	132.6	-3.0	417.1	557.8

GRANDE PRAIRIE WATER BALANCE SUMMARY - 150 mm Storage

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	429.3	510.8	147.2	0	+65.6	363.6	584.4
1970	255.3	528.1	236.6	15.1	-51.3	291.5	646.4
1971	574.7	527.7	0	0	+46.9	527.7	527.7
1972	512.0	479.6	46.8	82.9	-3.8	432.8	503.0
1973	379.0	502.8	99.5	1.9	-26.2	403.3	552.6
1974	460.6	491.8	73.6	74.0	-31.7	418.2	528.6
1975	392.9	494.8	178.6	0	+76.7	316.2	584.1
1976	535.2	536.4	0	30.7	-31.9	536.4	536.4
1977	456.5	510.8	4.5	0	-49.9	506.3	513.1
1978	332.7	526.1	185.3	0	-8.0	340.8	618.8
average	432.8	510.9	97.2	20.5	-1.4	413.7	559.5

WITH 18% PRECIPITATION CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	506.4	510.8	90.6	0	+86.1	420.2	556.1
1970	301.2	528.1	211.2	57.5	-73.2	316.9	633.7
1971	678.0	527.7	0	20.0	+130.2	527.7	527.7
1972	604.2	479.6	6.3	199.7	-68.9	473.3	482.8
1973	447.0	502.8	57.7	39.7	-37.8	445.1	531.7
1974	543.6	491.8	28.1	117.9	-38.1	463.7	505.9
1975	463.7	494.8	122.9	0	+91.7	371.9	556.3
1976	631.6	536.4	0	67.3	+27.9	536.4	536.4
1977	538.6	510.8	0	78.6	-50.9	510.8	510.8
1978	392.7	526.1	61.7	15.4	-87.0	464.4	557.0
average	510.7	510.9	57.9	59.6	-2.0	453.0	539.8

WITH 15% RAIN AND 50% SNOW CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	544.8	510.8	88.8	41.6	+81.1	422.0	555.2
1970	334.4	528.1	211.8	84.9	-66.8	316.3	634.0
1971	709.4	527.7	0	63.6	+118.0	527.7	527.7
1972	666.3	479.6	13.0	245.4	-45.8	466.6	486.1
1973	487.2	502.8	55.7	85.4	-45.3	447.1	530.7
1974	612.0	491.8	28.8	187.0	-38.1	463.0	506.2
1975	508.2	494.8	121.5	36.7	+97.2	373.3	555.6
1976	651.3	536.4	0	111.8	+3.1	536.4	536.4
1977	551.0	510.8	0	93.6	-53.5	510.8	510.8
1978	404.1	526.1	68.5	26.4	-79.7	457.6	560.4
average	546.9	510.9	58.8	97.6	-3.0	452.1	540.3

GRANDE PRAIRIE WATER BALANCE SUMMARY - 200 mm Storage

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	429.3	510.8	147.2	0	+65.6	363.6	584.4
1970	255.3	528.1	221.5	0	-51.3	306.6	638.9
1971	574.7	527.7	0	0	+46.9	527.7	527.7
1972	512.0	479.6	0	32.9	-0.6	479.6	479.6
1973	379.0	502.8	94.4	0	-29.4	408.4	550.0
1974	460.6	491.8	23.6	24.0	-31.7	468.2	503.6
1975	392.9	494.8	178.6	0	+76.7	316.2	584.1
1976	535.2	536.4	0	0	-1.2	536.4	536.4
1977	456.5	510.8	0	0	-54.4	510.8	510.8
1978	332.7	526.1	159.1	0	-34.2	367.0	605.7
average	432.8	510.9	82.4	5.7	-1.4	428.5	552.1

WITH 18% PRECIPITATION CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	506.4	510.8	90.6	0	+86.1	420.2	556.1
1970	301.2	528.1	161.2	7.5	-73.2	366.9	608.7
1971	678.0	527.7	0	0	+150.2	527.7	527.7
1972	604.2	479.6	0	169.7	-45.2	479.6	479.6
1973	447.0	502.8	7.7	33.4	-81.5	495.1	506.7
1974	543.6	491.8	0	67.9	-16.2	491.8	491.8
1975	463.7	494.8	101.0	0	+69.8	393.8	545.3
1976	631.6	536.4	0	17.3	+77.9	536.4	536.4
1977	538.6	510.8	0	78.6	-50.9	510.8	510.8
1978	392.7	526.1	11.7	15.4	-137.0	514.4	532.0
average	510.7	510.9	37.2	39.0	-2.0	473.7	529.5

WITH 15% RAIN AND 50% SNOW CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	544.8	510.8	47.2	0	+81.1	463.6	534.4
1970	334.4	528.1	161.8	34.9	-66.8	366.3	609.0
1971	709.4	527.7	0	13.6	+168.0	527.7	527.7
1972	666.3	479.6	0	245.4	-58.8	479.6	479.6
1973	487.2	502.8	5.7	72.4	-82.3	497.1	505.7
1974	612.0	491.8	0	137.0	-16.9	491.8	491.8
1975	508.2	494.8	75.1	7.9	+76.0	423.3	530.6
1976	651.3	536.4	0	61.8	+53.1	536.4	536.4
1977	551.0	510.8	0	93.6	-53.5	510.8	510.8
1978	404.1	526.1	18.5	26.4	-129.7	507.6	535.4
average	546.9	510.9	30.5	69.3	-3.0	480.4	526.1

GRANDE PRAIRIE WATER BALANCE SUMMARY - 250 mm Storage

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	429.3	510.8	147.2	0	+65.6	363.6	584.4
1970	255.3	528.1	221.5	0	-51.3	306.6	638.9
1971	574.7	527.7	0	0	+46.9	527.7	527.7
1972	512.0	479.6	0	0	+32.3	479.6	479.6
1973	379.0	502.8	61.5	0	-62.3	441.3	533.6
1974	460.6	491.8	0	0	-31.3	491.8	491.8
1975	392.9	494.8	178.2	0	+76.3	316.6	583.9
1976	535.2	536.4	0	0	-1.2	536.4	536.4
1977	456.5	510.8	0	0	-54.4	510.8	510.8
1978	332.7	526.1	159.1	0	-34.2	369.7	605.7
average	432.8	510.9	76.8	0	-1.4	434.1	549.3

WITH 18% PRECIPITATION CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	506.4	510.8	90.6	0	+86.1	420.2	556.1
1970	301.2	528.1	153.7	0	-73.2	374.4	605.0
1971	678.0	527.7	0	0	+150.2	527.7	527.7
1972	604.2	479.6	0	119.7	+4.8	479.6	479.6
1973	447.0	502.8	0	33.4	-89.2	502.8	502.8
1974	543.6	491.8	0	60.2	-8.5	491.8	491.8
1975	463.7	494.8	51.0	0	+19.8	443.8	520.3
1976	631.6	536.4	0	0	+95.2	536.4	536.4
1977	538.6	510.8	0	45.9	-18.2	510.8	510.8
1978	392.7	526.1	0	15.4	-148.7	526.1	526.1
average	510.7	510.9	29.5	27.5	+1.8	481.4	525.7

WITH 15% RAIN AND 50% SNOW CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	544.8	510.8	47.2	0	+81.1	463.6	534.4
1970	334.4	528.1	124.7	0	-66.8	400.9	591.7
1971	709.4	527.7	0	0	+181.6	527.7	527.7
1972	666.3	479.6	0	245.4	-58.8	479.6	479.6
1973	487.2	502.8	0	72.4	-88.0	502.8	502.8
1974	612.0	491.8	0	131.3	-11.2	491.8	491.8
1975	508.2	494.8	21.5	7.9	+26.0	473.3	505.6
1976	651.3	536.4	0	11.8	+103.1	536.4	536.4
1977	551.0	510.8	0	93.6	-53.5	510.8	510.8
1978	404.1	526.1	0	26.4	-148.2	526.1	526.1
average	546.9	510.9	19.6	58.9	-3.5	491.3	520.7

GRANDE PRAIRIE WATER BALANCE SUMMARY - 300 mm Storage

WITH 18% PRECIPITATION CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	506.4	510.8	90.6	0	+86.1	420.2	556.1
1970	301.2	528.1	153.7	0	-73.2	374.4	605.0
1971	678.0	527.7	0	0	+150.2	527.7	527.7
1972	604.2	479.6	0	69.7	+54.8	479.6	479.6
1973	447.0	502.8	0	33.4	-89.2	502.8	502.8
1974	543.6	491.8	0	60.2	-8.5	491.8	491.8
1975	463.7	494.8	1.0	0	-30.2	493.8	495.3
1976	631.6	536.4	0	0	+95.2	536.4	536.4
1977	538.6	510.8	0	0	+27.7	510.8	510.8
1978	392.7	526.1	0	11.3	-144.6	526.1	526.1
average	510.7	510.9	24.5	17.5	+6.8	486.4	523.2

WITH 15% RAIN AND 50% SNOW CORRECTION FACTOR

YEAR	Ppt.	P.E.	D.	S.	St. Ch.	E.T.	Lake Evap.
1969	544.8	510.8	47.2	0	+81.1	463.6	534.4
1970	334.4	528.1	127.2	0	-66.8	400.9	591.7
1971	709.4	527.7	0	0	+181.6	527.7	527.7
1972	666.3	479.6	0	159.0	+27.6	479.6	479.6
1973	487.2	502.8	0	72.4	-88.0	502.8	502.8
1974	612.0	491.8	0	131.3	-11.2	491.8	491.8
1975	508.2	494.8	0	7.9	+4.5	494.8	494.8
1976	651.3	536.4	0	0	+114.9	536.4	536.4
1977	551.0	510.8	0	83.9	-43.8	510.8	510.8
1978	404.1	526.1	0	26.4	-148.2	526.1	526.1
average	546.9	510.9	17.4	48.1	+5.2	493.5	519.6

APPENDIX 3

STREAMFLOW RECORDS

COMPARISON OF SPRING CREEK AND STURGEON CREEK STREAMFLOW, 1978

	JUNE		JULY	
	DISCHARGE	SURPLUS	DISCHARGE	SURPLUS
Spring Creek	1.317 $m^3\ s^{-1}$	30.45 mm	0.051 $m^3\ s^{-1}$	1.22 mm
Sturgeon Creek	5.442 $m^3\ s^{-1}$	22.75 mm	3.689 $m^3\ s^{-1}$	15.94 mm

sources: Environment Canada, 1979
Author's Measurements, 1978

STREAMFLOW RECORD FOR SPRING CREEK, 1969-1978
(in m^3 s^{-1})

basin area -
112.1 km^2

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL	$\bar{x}$	mm S
1969	-	-	0	1.617	0.413	0.028	0.057	0.002	0.031	0.034	-	-	2.182	0.182	51.20
1970	-	-	0.037	1.124	0.615	0.057	0.003	0	0	0	-	-	1.836	0.153	43.04
1971	-	-	0.001	0.436	0.142	1.781	1.252	0.005	0.006	0.015	-	-	3.638	0.303	85.24
1972	-	-	0.108	1.807	0.753	0.75	0.164	0.013	0.007	0.028	0.003*	-	3.633	0.303	85.24
1973	-	-	0.018	1.399	0.646	0.852	0.082	0.016	0.042	0.093	0.014*	-	3.162	0.264	74.27
1974	-	-	0.007	4.475	1.906	0.065	0.004	0.001	0.002	0.007	-	-	6.467	0.539	151.63
1975	-	-	0*	0.459*	0.379	0.147	0.105	0.006	0.020	0.034	0.017*	-	1.167	0.097	27.29
1976	-	-	0.054*	2.05	0.348	2.447	0.278	2.665	0.297	0.139	0.025*	-	8.303	0.692	194.67
1977	-	-	0	3.059	2.263	0.493	1.181	0.142	0.082	0.365	0.051*	-	7.636	0.636	178.92
1978	-	-	0.085*	1.608*	1.215	1.317	0.051	0.022	0.235	0.122	0.028*	-	4.683	0.390	109.71

* figure extrapolated from incomplete source data

sources: Environment Canada, 1979 & 1978 and
Fisheries and Environment Canada, 1977

STREAMFLOW RECORD FOR BEAVERLODGE RIVER, 1969-1978
(in $m^3 s^{-1}$)

basin area -
1606 km^2

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL	$\overline{x}$	mm S
1969	-	-	0.007	26.108	16.622	1.790	0.824	0.022	2.438	2.801	-	-	50.612	4.218	82.83
1970	-	-	4.134	14.470	7.617	2.013	0.125	0.001	0	0.006	-	-	28.366	2.364	46.42
1971	-	-	0	8.467	4.304	15.093	21.379	2.027	0.292	0.532	-	-	52.094	4.341	85.24
1972	-	-	4.672	21.351	23.928	5.862	0.991	0.252	0.133	3.596	-	-	60.785	5.065	99.46
1973	-	-	0.156	27.864	11.327	2.115	0.221	0.016	0.009	0.170	0.071	-	41.949	3.496	68.65
1974	-	-	0.071	34.829	39.643	4.219	0.558	0.091	0.045	0.082	0.023	-	79.561	6.630	130.19
1975	-	-	0.008	6.853	6.400	1.008	0.062	0	0	0	-	-	14.331	1.194	23.45
1976	-	-	0.001	15.008	3.426	4.389	8.976	15.178	3.540	1.181	-	-	51.699	4.308	84.59
1977	-	0.048	0.272	15.121	20.530	15.348	3.625	0.903	0.309	1.269	-	-	57.425	4.785	93.96
1978	-	0.014	1.138	4.644	2.682	1.070	0.272	0.042	0.051	0.170	-	-	10.083	0.840	16.49

STREAMFLOW RECORD FOR WEST PRAIRIE RIVER, 1969-1978
(in $m^3 s^{-1}$)

basin area -
1163 km^2

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL	$\bar{x}$	mm S
1969	-	-	0.031	12.318	5.182	1.005	0.122	0.071	3.823	1.906	-	-	24.458	3.057[1]	55.641
1970	-	-	0.122	19.850	18.179	7.759	4.870	2.945	0.852	0.903	0.507	0.156	56.143	5.614[2]	126.37
1971	0.108	0.074	0.034	26.051	7.391	23.305	29.166	1.685	0.631	0.688	0.241	0.201	89.575	7.447	201.93
1972	0.116	0.108	0.337	9.033	14.243	7.306	4.163	2.554	1.155	1.144	0.799	0.289	41.247	3.455	43.69
1973	0.227	0.161	0.207	19.793	18.123	18.944	2.917	5.465	1.841	2.665	1.591	0.439	72.373	6.031	163.54
1974	0.232	0.232	0.215	41.059	33.980	2.945	7.079	0.759	0.934	0.816	0.498	0.278	89.027	7.419	201.17
1975	0.178	0.091	0.088	5.097	8.070	12.629	9.741	1.504	5.408	1.152	1.039	0.450	45.447	3.794	102.88
1976	0.201	0.184	0.173	28.600	9.401	24.890	13.479	34.546	9.486	2.515	1.051	0.377	124.903	10.392	281.79
1977	0.306	0.416	0.461	24.097	33.414	17.528	14.781	1.736	2.127	0.849	0.532	0.170	96.417	8.042	218.07
1978	0.079	0.076	0.365	9.486	12.827	22.342	2.098	0.702	10.675	2.888	1.472	0.711	63.721	5.295	143.58

1. 8 month mean
2. 10 month mean

COMPARISON OF RIVER BASIN SURPLUS AND PRECIPITATION RECORDS, 1969-1978

	Spring Creek/Grande Prairie			Beaverlodge River/Grande Prairie			West Prairie River/High Prairie		
	S[1]	Ppt[2]	%[3]	S	Ppt	%	S	Ppt	%
1969	51.20	429.3	11.93	82.83	429.3	19.29	55.64	467.4	11.90
1970	43.04	255.3	16.86	46.42	255.3	18.18	126.37	486.7	25.96
1971	85.24	574.7	14.83	85.24	574.7	14.83	201.93	527.6	38.27
1972	85.24	512.0	16.65	99.46	512.0	19.34	93.69	564.6	16.59
1973	74.27	379.0	19.60	68.65	379.0	18.11	163.54	601.2	27.20
1974	151.63	460.6	32.92	130.19	460.6	28.27	201.17	571.0	35.23
1975	27.29	392.9	6.95	23.45	392.9	5.97	102.88	547.6	18.79
1976	194.67	535.2	36.37	84.59	535.2	15.81	281.79	729.5	38.63
1977	178.92	456.5	39.19	93.96	456.5	20.58	218.07	633.2	34.44
1978	109.71	332.7	32.98	16.49	332.7	4.96	143.58	475.2	30.21

1. surplus calculated from Environment Canada, 1979 & 1978 and Fisheries and Environment Canada, 1977.
2. precipitation from Atmospheric Environment Service, 1978.
3. percentage of precipitation which entered the river as surplus.

APPENDIX 4

WATER QUALITY DATA - 1978

TOTAL ALKALINITY AS $CaCO_3$

($mg\ l^{-1}$)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	53.6	-	-	52.2	-	-	52.9	-	-	-	58.7	56.8	54.0	48.2	47.1
B	-	-	-	-	-	54.8	-	57.8	-	53.4	54.2	-	54.0	47.4	53.6
C	-	54.1	-	52.0	-	-	53.4	-	55.0	-	56.0	-	58.1	49.6	54.0
D	52.5	56.8	52.1	51.3	49.9	50.3	50.9	52.8	53.3	53.9	55.2	53.1	63.9	48.1	53.2
E	54.9	54.8	49.4	52.9	54.1	48.8	50.8	55.6	54.7	57.6	59.8	59.4	55.3	69.6	55.6
F	56.0	-	55.8	-	-	51.3	-	-	-	-	53.7	56.0	57.2	49.1	54.2
G	-	53.9	-	50.8	-	51.7	51.3	-	-	55.8	61.0	-	53.9	49.7	61.2
H	-	-	45.4	-	49.9	-	-	56.3	55.1	-	58.9	-	56.1	49.2	53.0
I	-	48.1	-	-	48.6	-	-	57.0	-	-	75.1	-	62.6	63.8	59.2
J	43.0	-	45.0	-	49.0	-	-	-	55.3	56.7	58.3	69.0	53.4	46.8	52.9
date average	52.0	53.5	49.5	51.8	50.3	51.4	51.9	55.9	54.7	55.5	59.1	58.9	56.9	52.2	
K	-	-	-	-	-	-	-	-	-	-	62.9	69.0	74.8	53.2	65.0
L	-	-	-	-	-	-	-	-	-	-	-	-	45.4	-	-

lake average	54.4
main basin average	54.1
western arm average	55.0

CHLORIDE
(mg l^{-1})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	3.67	-	-	5.05	-	4.59	4.13	-	-	-	3.21	3.67	3.21	2.75	3.79
B	-	-	-	-	-	3.21	-	3.67	-	3.21	2.29	-	3.67	3.21	3.21
C	-	4.59	-	4.59	-	-	3.21	-	3.67	-	2.75	-	3.67	3.67	3.74
D	4.13	4.13	5.51	4.59	4.13	4.59	4.13	3.67	3.67	3.21	3.21	3.67	3.67	3.21	3.97
E	4.13	4.59	5.51	4.13	4.59	7.80	3.67	4.59	5.05	3.21	2.29	4.13	4.59	3.21	4.39
F	4.59	-	4.59	-	-	5.51	-	-	-	-	3.21	4.59	5.05	3.67	4.46
G	-	4.59	-	4.13	-	-	3.67	-	-	3.67	3.21	-	4.59	3.21	3.87
H	-	-	3.21	-	4.13	-	-	3.67	3.67	-	3.21	-	4.59	4.59	3.87
I	-	5.97	-	-	4.13	-	-	4.59	-	-	4.59	-	4.59	3.67	4.59
J	5.05	-	4.59	-	3.67	-	-	-	3.21	3.21	3.21	5.51	5.51	4.13	4.23
date average	4.31	4.77	4.68	4.50	4.13	5.14	3.76	4.04	3.85	3.30	3.12	4.31	4.31	3.53	
K	-	-	-	-	-	-	-	-	-	-	4.59	4.13	5.05	2.75	4.13
L	-	-	-	-	-	-	-	-	-	-	-	-	3.67	-	-

lake average	4.01
main basin average	3.92
western arm average	4.23

CHLOROPHYLL *a*
(mg m^{-3})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	19.8	17.6	10.2	0.9	6.9	6.1	15.1	9.0	119.1	12.5	42.9	31.3	21.4	38.9	25.1
B	9.9	14.1	14.1	1.3	5.0	3.9	17.0	13.2	23.1	23.3	18.9	54.4	50.2	21.4	19.3
C	9.0	19.2	9.4	4.5	6.6	5.9	18.1	16.0	11.8	20.5	8.0	69.2	124.1+	40.8	25.9
D	9.4	9.4	8.0	5.2	7.9	12.4	23.2	20.5	16.0	26.1	32.4	19.0	76.1	18.4	20.3
E	2.4	1.5	0.7	1.7	2.4	5.4	2.4	2.2	4.1	6.7	14.3	27.6	30.2	14.3	8.3
F	14.6	8.5	9.4	2.3	6.8	6.9	11.4	8.0	49.5	20.3	12.8	26.3	33.3	6.6	15.5
G	12.6	14.1	7.1	1.8	12.4	9.4	9.8	11.2	65.9	11.8	51.1	51.9	33.9	18.8	22.3
H	-	-	10.4	8.8	11.4	16.0	10.8	11.1	47.8	44.5+	17.7	98.9+	119.1+	16.5+	34.4
I	13.7	17.6	5.4	1.1	5.1	4.5	5.1	6.9	47.8	23.2	5.2	10.4	69.4+	23.7	17.1
J	10.4	10.8	6.6	4.2	11.4	9.0	12.6	14.6	29.7	14.3	66.3	150.5+	37.9+	12.4	27.9
date average	11.3	12.5	8.1	3.2	7.6	8.0	12.6	11.3	41.5	20.3	27.0	54.0	59.6	21.2	
K	-	-	-	-	-	-	-	-	-	-	19.7	9.5	16.0+	-	15.1
L	-	-	-	-	-	-	-	-	-	-	-	-	46.9	-	-

lake average	21.3
main basin average	19.5
western arm average	26.5

+ two filters used

COLOR
(TCU)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	65	-	-	80	-	80	72	-	-	-	96	80	80	91	80.5
B	-	-	-	-	-	116	-	77	-	72	85	-	80	91	86.8
C	-	72	-	80	-	-	80	-	80	-	87	-	85	87	81.6
D	72	96	105	80	87	91	187	96	80	87	87	80	127	91	97.6
E	80	285	310	283	285	275	290	205	283	283	205	112	87	150	223.8
F	72	-	80	-	-	80	-	-	-	-	65	72	80	80	75.6
G	-	77	-	80	-	-	77	-	-	85	87	-	80	80	80.9
H	-	-	127	-	164	-	-	130	164	-	127	-	116	105	133.3
I	-	150	-	-	150	-	-	157	-	-	232	-	127	127	157.2
J	105	-	120	-	123	-	-	-	112	127	120	157	105	96	118.3
date average	78.8	136.0	148.4	120.6	161.8	128.4	141.2	133.0	143.8	130.8	119.1	100.2	96.7	99.8	
K	-	-	-	-	-	-	-	-	-	-	272	275	290	546	345.8
L	-	-	-	-	-	-	-	-	-	-	-	-	359	-	-

lake average	113.6
main basin average	103.8
western arm average	136.3

TOTAL DISSOLVED SOLIDS
($mg\ l^{-1}$)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	-	-	-	107.0	-	119.8	151.7	-	-	-	130.9	76.7	148.8	104.3	119.89
B	-	-	-	-	-	151.3	-	160.6	-	103.3	120.1	-	181.7	130.7	141.28
C	-	125.0	-	100.0	-	-	115.1	-	97.0	-	111.2	-	136.8	154.7	119.97
D	-	127.6	176.3	127.2	125.9	152.2	109.0	127.8	142.8	142.3	117.4	91.9	163.9	128.1	133.26
E	-	157.3	158.8	134.7	153.1	150.3	124.8	161.6	194.0	123.0	147.2	121.6	149.0	165.8	149.32
F	-	-	174.6	-	-	135.7	-	-	-	-	141.3	84.4	146.4	107.0	131.57
G	-	135.8	-	134.4	-	-	132.7	-	-	115.6	131.9	-	120.2	120.8	127.34
H	-	-	114.1	-	158.2	-	-	163.0	295.4	-	132.7	-	144.2	182.8	170.06
I	-	251.2	-	-	95.7	-	-	142.6	-	-	172.9	-	168.5	147.8	163.12
J	-	-	131.5	-	123.2	-	-	-	151.8	141.8	134.8	135.4	135.6	132.9	135.88
date average	-	159.38	151.06	120.66	131.22	141.86	126.66	151.12	176.20	125.14	134.04	102.0	149.51	137.49	
K	-	-	-	-	-	-	-	-	-	-	180.0	161.7	145.0	198.9	171.40
L	-	-	-	-	-	-	-	-	-	-	-	-	181.8	-	-

lake average	139.17
main basin average	131.80
western arm average	156.35

TOTAL HARDNESS AS $CaCO_3$

($mg\ \ell^{-1}$)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	76	-	-	84	-	72	60	-	-	-	68	60	60	60	67.5
B	-	-	-	-	-	76	-	64	-	64	68	-	68	72	68.7
C	-	72	-	80	-	-	60	-	64	-	68	-	64	60	66.9
D	84	64	164	80	72	72	60	68	64	72	72	68	68	64	76.6
E	92	76	88	92	76	68	60	64	64	68	72	64	72	84	74.3
F	76	-	104	-	-	84	-	-	-	-	68	72	60	68	76.0
G	-	76	-	88	-	-	68	-	-	68	64	-	64	68	70.9
H	-	-	108	-	76	-	-	68	76	-	72	-	60	72	76.0
I	-	80	-	-	64	-	-	72	-	-	80	-	72	80	74.7
J	80	-	136	-	60	-	-	-	60	68	68	64	64	64	73.8
date average	81.6	73.6	120.0	84.8	69.6	74.4	61.6	67.2	65.6	68.0	70	65.6	65.2	69.2	
K	-	-	-	-	-	-	-	-	-	-	68	76	80	64	72.0
L	-	-	-	-	-	-	-	-	-	-	-	-	64	-	-

lake average	72.50
main basin average	71.60
western arm average	74.83

IRON
(mg l^{-1})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	0.42	0.31	0.24	0.08	0.13	0.16	0.14	0.08	0.07	0.11	0.07	0.07	0.12	0.04	0.15
B	0.32	0.33	0.21	0.09	0.12	0.21	0.21	0.07	0.05	0.18	0.14	0.07	0.11	0.05	0.15
C	0.33	0.28	0.59	0.10	0.10	0.19	0.18	0.04	0.07	0.13	0.09	0.08	0.14	0.07	0.17
D	0.40	0.40	0.46	0.10	0.10	0.14	0.42	0.12	0.04	0.16	0.13	0.07	0.17	0.18	0.21
E	0.92	1.19	1.12	0.83	0.99	0.78	0.79	0.72	0.80	0.74	0.48	0.22	0.32	0.27	0.73
F	0.31	0.22	0.19	0.16	0.10	0.15	0.13	0.10	0.23	0.13	0.10	0.09	0.11	0.07	0.15
G	0.30	0.26	0.29	0.15	0.11	0.14	0.12	0.08	0.04	0.03	0.10	0.08	0.09	0.12	0.14
H	-	-	0.27	0.25	0.36	0.32	0.38	0.24	0.24	0.37	0.11	0.14	0.08	0.13	0.24
I	0.41	0.29	0.50	0.34	0.23	0.37	0.78	0.25	0.18	0.36	0.34	0.57	0.13	0.28	0.36
J	0.41	0.27	0.28	0.18	0.20	0.36	0.25	0.17	0.17	0.13	0.23	0.10	0.06	0.13	0.21
date average	0.42	0.39	0.42	0.23	0.24	0.28	0.34	0.19	0.19	0.23	0.18	0.15	0.13	0.13	
K	-	-	-	-	-	-	-	-	-	-	0.92	0.78	0.95	+3.0	1.41
L	-	-	-	-	-	-	-	-	-	-	-	-	0.58	-	-

lake average	0.25
main basin average	0.24
western arm average	0.27

TOTAL KJELDAHL NITROGEN
(mg l^{-1})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	0.84	-	-	0.73	-	0.85	1.09	-	-	-	1.99	1.27	1.26	2.04	1.26
B	-	-	-	-	-	0.81	-	0.73	-	1.05	1.32	-	1.28	1.43	1.10
C	-	1.25	-	0.71	-	-	1.75	-	1.22	-	1.26	-	2.17	1.61	1.42
D	0.81	0.97	0.92	0.71	0.82	0.95	1.67	0.91	1.58	1.36	1.57	1.19	3.30	1.14	1.28
E	0.98	1.34	1.14	1.14	1.30	1.43	1.50	1.16	1.67	1.42	0.76	2.08	1.30	0.11	1.24
F	0.86	-	0.39	-	-	0.93	-	-	-	-	1.02	1.12	0.63	0.36	0.76
G	-	1.02	-	0.66	-	-	1.10	-	-	0.96	2.22	-	1.46	1.14	1.22
H	-	-	0.90	-	1.58	-	-	1.47	2.47	-	1.94	-	3.24	5.52	2.45
I	-	2.92	-	-	1.34	-	-	1.33	-	-	1.79	-	2.25	1.55	1.86
J	0.95	-	0.91	-	1.05	-	-	-	1.85	2.28	2.55	6.08	2.43	1.89	2.22
date average	0.89	1.50	0.85	0.79	1.42	0.99	1.42	1.12	1.76	1.41	1.64	2.35	1.93	1.68	
K	-	-	-	-	-	-	-	-	-	-	1.42	1.48	1.54	1.57	1.50
L	-	-	-	-	-	-	-	-	-	-	-	-	3.73	-	-

lake average	1.48
main basin average	1.18
western arm average	2.18

DISSOLVED OXYGEN
(mg l^{-1})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	10.37	8.32	8.89	9.01	8.59	8.81	8.74	8.48	9.49	10.4	9.38	8.93	7.01	7.46	8.85
B	10.26	8.44	9.80	9.92	8.36	9.27	8.59	9.27	9.72	9.49	8.93	9.27	7.46	8.25	9.07
C	10.49	9.58	9.80	9.12	9.04	9.49	8.93	9.61	8.02	9.61	9.27	9.61	8.14	8.81	9.25
D	10.03	9.35	9.35	9.58	9.04	9.49	9.38	9.04	8.70	9.49	7.35	6.55	10.40	8.25	9.00
E	8.44	8.21	5.70	5.47	6.55	6.89	6.22	6.10	6.89	6.67	6.78	9.83	6.55	5.54	6.85
F	11.06	-	8.66	8.78	8.21	8.59	9.27	-	7.57	10.4	12.66	12.77	10.09	7.68	9.65
G	-	9.23	7.30	10.18	8.81	8.70	9.61	9.15	8.36	9.94	8.02	13.56	8.70	6.78	9.10
H	-	-	7.41	7.52	7.46	8.14	8.14	7.8	9.72	10.17	8.36	13.56	9.72	7.01	8.75
I	9.01	8.21	7.07	8.09	7.91	8.59	8.59	9.83	10.40	11.75	9.38	9.38	9.72	8.14	9.01
J	9.80	8.32	8.66	8.44	8.36	8.14	9.15	9.04	9.94	11.41	9.04	15.48	9.72	8.25	9.55
date average	9.93	8.71	8.26	8.61	8.23	8.61	8.66	8.70	8.88	9.93	8.92	10.89	8.75	7.62	
K	-	-	-	-	-	-	-	-	-	-	7.68	6.89	5.54	-	6.70
L	-	-	-	-	-	-	-	-	-	-	-	-	4.29	-	-

lake average	8.91
main basin average	8.82
western arm average	9.10

pH
(units)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	-	-	-	7.80	7.80	7.70	7.60	8.20	7.40	8.38	8.25	7.08	8.35	6.49	7.73
B	-	-	-	7.50	7.90	7.90	7.90	8.30	8.10	8.30	8.15	7.00	8.20	6.70	7.81
C	-	-	-	7.70	8.10	8.40	8.00	8.50	7.45	8.40	8.51	7.35	8.62	6.80	7.98
D	-	-	-	7.80	8.40	8.00	8.00	8.10	7.60	8.55	7.00	6.60	+10.00	6.65	7.88
E	-	-	-	7.70	7.60	7.30	7.20	8.10	7.20	7.20	6.55	7.00	8.34	6.50	7.34
F	-	-	-	7.70	7.60	7.90	7.40	7.80	7.30	8.45	6.75	7.30	8.89	7.10	7.65
G	-	-	-	7.50	8.00	7.90	8.00	8.50	7.70	8.10	6.96	9.30	8.68	6.80	7.95
H	-	-	-	7.80	7.60	7.70	7.70	7.90	8.10	9.18	9.10	9.70	9.90	6.59	8.30
I	-	-	-	7.90	8.20	8.10	7.60	8.50	8.78	9.90	9.50	9.13	9.90	6.90	8.58
J	-	-	-	7.70	8.00	7.80	8.30	8.30	8.40	9.80	9.43	9.60	10.00	6.75	8.55
date average	-	-	-	7.71	7.92	7.87	7.77	8.22	7.80	8.63	8.02	8.01	9.09	6.73	
K	-	-	-	-	-	-	-	-	-	-	6.58	6.90	6.58	6.38	6.61
L	-	-	-	-	-	-	-	-	-	-	-	-	6.42	-	-

lake average	7.98
main basin average	7.76
western arm average	8.48

ORTHO PHOSPHATE
(mg l^{-1})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	0.35	-	-	0.12	-	0.14	0.16	-	-	-	0.13	0.27	0.33	0.24	0.22
B	-	-	-	-	-	0.16	-	0.13	-	0.13	0.12	-	0.33	0.28	0.19
C	-	0.20	-	0.08	-	-	0.18	-	0.11	-	0.10	-	0.31	0.25	0.18
D	0.19	0.23	0.25	0.09	0.09	0.27	0.26	0.16	0.09	0.16	0.21	0.07	0.40	0.16	0.19
E	0.23	0.55	0.46	0.43	0.50	0.51	0.43	0.43	0.47	0.42	0.28	0.24	0.41	0.41	0.41
F	0.13	-	0.11	-	-	0.31	-	-	-	-	0.22	0.19	0.23	0.17	0.19
G	-	0.15	-	0.10	-	-	0.13	-	-	0.10	0.24	-	0.25	0.17	0.16
H	-	-	0.11	-	0.22	-	-	0.24	0.68	-	0.12	-	0.23	0.26	0.27
I	-	0.42	-	-	0.13	-	-	0.21	-	-	0.67	-	0.40	0.19	0.34
J	0.13	-	0.14	-	0.08	-	-	-	0.19	0.11	0.16	0.50	0.18	0.07	0.17
date average	0.21	0.31	0.21	0.16	0.20	0.28	0.23	0.23	0.31	0.18	0.23	0.25	0.31	0.22	
K	-	-	-	-	-	-	-	-	-	-	0.32	0.50	0.59	1.58	0.75
L	-	-	-	-	-	-	-	-	-	-	-	-	0.66	-	-

lake average	0.23
main basin average	0.22
western arm average	0.26

TOTAL PHOSPHATE
(mg l^{-1})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	0.60	-	-	0.34	-	0.33	0.38	-	-	-	0.49	0.51	0.67	0.58	0.49
B	-	-	-	-	-	0.38	-	0.34	-	0.49	0.37	-	0.77	0.87	0.54
C	-	0.56	-	0.28	-	-	0.46	-	0.36	-	0.34	-	0.75	0.72	0.50
D	0.52	0.48	0.59	0.31	0.35	0.57	0.53	0.43	0.33	0.69	0.49	0.31	0.99	0.55	0.51
E	0.54	0.88	0.89	0.75	0.88	0.87	0.70	0.70	0.87	0.87	0.63	0.52	0.71	0.72	0.75
F	0.50	-	0.44	-	-	0.59	-	-	-	-	0.50	0.42	0.50	0.57	0.50
G	-	0.39	-	0.33	-	-	0.28	-	-	0.52	0.61	-	0.51	0.40	0.43
H	-	-	0.38	-	0.56	-	-	0.53	1.02	-	0.54	-	0.76	1.02	0.69
I	-	1.11	-	-	0.44	-	-	0.43	-	-	1.00	-	0.74	0.46	0.70
J	0.45	-	0.40	-	0.35	-	-	-	0.49	0.50	0.61	1.14	0.59	0.54	0.56
date average	0.52	0.68	0.54	0.40	0.52	0.55	0.47	0.49	0.61	0.61	0.56	0.58	0.70	0.64	
K	-	-	-	-	-	-	-	-	-	-	0.64	0.79	0.87	2.42	1.18
L	-	-	-	-	-	-	-	-	-	-	-	-	1.24	-	-

lake average	0.57
main basin average	0.53
western arm average	0.65

POTASSIUM
(mg l^{-1})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	3	-	-	6	-	2	4	-	-	-	4	5	4	4	4.00
B	-	-	-	-	-	2	-	4	-	6	4	-	4	4	4.00
C	-	4	-	6	-	-	4	-	4	-	4	-	4	4	4.29
D	3	4	6	6	2	2	4	4	4	6	4	5	4	4	4.14
E	3	4	5	5	1	2	3	3	3	6	3	5	4	4	3.64
F	3	-	6	-	-	2	-	-	-	-	4	5	4	4	4.00
G	-	4	-	6	-	-	4	-	-	5	4	-	4	4	4.43
H	-	-	6	-	2	-	-	4	4	-	4	-	4	4	4.00
I	-	4	-	-	2	-	-	3	-	-	2	-	4	4	3.17
J	3	-	6	-	2	-	-	-	4	5	4	5	4	4	4.11
date average	3.0	4.0	5.8	5.8	1.8	2.0	3.8	3.6	3.8	5.6	3.7	5.0	4.0	4.0	
K	-	-	-	-	-	-	-	-	-	-	3	3	3	4	3.25
L	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-

lake average	3.98
main basin average	4.07
western arm average	3.76

SECCHI
(m)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	1.00	1.05	1.40	1.50	2.00	1.75	+1.30	+1.50	-	+1.00	+1.00	+0.75	+0.80	-	+1.25
B	+0.90	1.20	1.20	+1.00	+1.00	1.00	0.65	+0.75	-	+0.75	+0.75	+0.50	+0.50	-	+0.85
C	1.00	0.80	0.70	+0.75	+1.00	0.90	0.75	+0.75	-	+1.00	+0.75	+0.20	+0.30	-	+0.74
D	1.30	+0.60	+0.60	+0.60	+0.50	0.60	0.50	+0.50	-	+1.00	+0.50	+0.25	0.35	-	+0.61
E	0.60	0.70	0.50	0.70	0.65	0.40	0.50	0.60	-	0.80	+0.70	0.70	+0.55	-	+0.62
F	1.00	1.40	1.30	1.50	1.50	1.40	1.00	1.40	-	+1.00	+1.00	+0.75	1.10	-	+1.20
G	1.00	1.10	1.40	1.60	1.40	1.30	+1.05	+1.00	-	+1.00	+0.70	+0.80	+0.80	-	+1.10
H	-	-	0.80	0.40	0.40	0.55	0.40	0.55	-	0.25	0.45	0.35	0.25	-	0.44
I	0.60	0.60	0.50	0.50	0.65	0.70	0.55	+0.75	-	0.50	0.50	0.35	0.45	-	+0.55
J	0.60	0.80	0.80	0.70	0.80	0.60	1.00	0.85	-	0.60	0.55	0.30	0.40	-	0.67
date average	0.89	0.92	0.92	0.93	0.99	0.92	0.77	0.87	-	0.79	0.69	0.50	0.55	-	
K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

lake average	0.81
main basin average	0.91
western arm average	0.55

SILICA
(mg l^{-1})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	0.63	-	-	0.37	-	0.51	0.63	-	-	-	0.41	0.95	1.55	3.90	1.12
B	-	-	-	-	-	1.18	-	0.35	-	0.32	0.34	-	1.24	3.60	1.17
C	0.72	-	-	0.41	-	-	0.45	-	0.44	-	0.45	-	1.26	3.90	1.09
D	0.91	0.50	0.50	0.39	0.32	0.36	0.82	0.50	0.48	0.32	0.39	0.78	1.04	3.00	0.74
E	0.95	2.35	2.25	1.50	1.85	1.11	1.50	1.07	1.21	1.14	1.03	0.93	1.01	2.20	1.44
F	0.52	-	0.52	-	-	0.62	-	-	-	-	0.78	1.04	1.60	3.90	1.28
G	-	0.36	-	0.44	-	-	0.54	-	-	0.34	0.51	-	1.37	3.85	1.06
H	-	-	0.87	-	0.52	-	-	1.07	2.20	-	1.77	-	3.00	3.75	1.88
I	-	0	-	-	0.44	-	-	0.81	-	-	0.41	-	1.50	1.80	0.83
J	-	0.45	0.70	-	0.33	-	-	-	1.08	1.00	1.23	1.66	2.55	5.10	1.57
date average	0.75	0.73	0.97	0.62	0.69	0.76	0.79	0.76	1.08	0.62	0.73	1.07	1.61	3.50	
K	-	-	-	-	-	-	-	-	-	-	1.52	1.75	1.75	3.05	2.02
L	-	-	-	-	-	-	-	-	-	-	-	-	1.23	-	-

lake average	1.22
main basin average	1.13
western arm average	1.43

SODIUM
(mg l^{-1})

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	7	-	-	6	-	2	7	-	-	-	6	6	5	5	5.50
B	-	-	-	-	-	2	-	6	-	6	6	-	6	5	5.17
C	-	7	-	6	-	-	6	-	6	-	6	-	5	5	5.86
D	6	7	6	5	3	2	6	6	6	6	6	6	7	5	5.50
E	6	6	4	4	2	2	4	5	5	7	6	6	6	5	4.86
F	5	-	6	-	-	2	-	-	-	-	6	6	6	5	5.14
G	-	6	-	6	-	-	6	-	-	6	6	-	5	5	5.71
H	-	-	6	-	4	-	-	6	6	-	6	-	6	6	5.71
I	-	8	-	-	6	-	-	6	-	-	9	-	8	8	7.50
J	7	-	6	-	4	-	-	-	6	6	6	6	6	6	5.89
date average	6.2	6.8	5.6	5.4	3.8	2.0	5.8	5.8	5.8	6.2	6.3	6.0	6.0	5.5	
K	-	-	-	-	-	-	-	-	-	-	6	5	6	5	5.50
L	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-

lake average	5.68
main basin average	5.39
western arm average	6.37

SPECIFIC CONDUCTANCE
(micromhos)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	159	160	-	-	160	150	150	155	150	175	155	185	165	-	160.36
B	165	158	-	-	160	180	170	150	150	160	150	185	165	-	163.00
C	150	155	-	-	150	150	150	150	155	165	160	185	165	-	157.73
D	155	175	-	-	160	150	145	150	155	190	160	180	175	-	163.18
E	150	150	-	-	140	130	135	130	150	190	160	175	170	-	152.73
F	159	155	-	-	150	160	160	160	-	155	165	165	155	-	158.40
G	160	160	-	-	155	155	160	180	-	160	165	185	140	-	162.00
H	-	-	-	-	155	160	155	160	160	160	150	190	180	-	163.33
I	143	135	-	-	160	160	190	160	160	200	195	245	180	-	175.27
J	140	135	-	-	160	145	160	160	170	180	165	250	155	-	165.45
date average	153.44	153.67	-	-	155	154	157.5	155.5	156.25	173.5	162.5	194.5	165	-	
K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

lake average	162.15
main basin average	159.63
western arm average	168.02

SULFATE
($mg\ l^{-1}$)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	11	-	-	10	-	12	11	-	-	-	11	10	10	13	11.00
B	-	-	-	-	-	14	-	10	-	11	10	-	11	13	11.50
C	-	13	-	11	-	-	12	-	11	-	11	-	11	13	11.71
D	11	12	10	11	12	11	9	10	10	11	10	10	11	13	10.79
E	12	11	9	9	8	6	6	5	8	6	8	10	11	10	8.50
F	11	-	12	-	-	12	-	-	-	-	10	10	11	13	11.29
G	-	12	-	11	-	-	11	-	-	11	11	-	11	13	11.43
H	-	-	12	-	14	-	-	11	11	-	11	-	11	13	11.86
I	-	32	-	-	14	-	-	11	-	-	9	-	10	11	14.50
J	12	-	13	-	13	-	-	-	11	12	11	9	10	15	11.78
date average	11.4	16.0	11.2	10.4	12.2	11.0	9.8	9.4	10.2	10.2	10.2	9.8	10.7	12.7	
K	-	-	-	-	-	-	-	-	-	-	8	6	7	0	5.25
L	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-

lake average	11.44
main basin average	10.89
western arm average	12.71

TEMPERATURE
($^{\circ}$C)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept 16	site average
A	10.4	10.8	12.6	17.0	15.8	16.1	17.6	19.3	18.6	21.1	20.4	22.3	19.8	13.4	16.80
B	11.2	10.5	12.2	19.7	15.8	15.2	18.2	19.2	18.6	21.6	20.6	21.7	18.6	12.3	16.81
C	10.5	10.6	12.8	20.6	15.7	15.5	19.0	19.7	18.1	21.4	20.8	22.0	19.1	12.2	17.00
D	9.7	9.5	12.5	20.2	-	15.6	18.0	20.2	18.2	20.8	20.0	19.4	20.7	10.5	16.56
E	9.6	12.0	12.3	17.8	-	16.7	18.8	19.7	18.2	20.2	18.4	18.5	20.7	11.5	16.49
F	10.3	12.4	12.0	20.8	17.5	16.6	18.7	20.1	-	21.6	20.5	23.1	21.4	13.4	17.57
G	10.6	13.3	12.0	18.8	17.8	16.6	17.8	19.7	-	19.9	20.3	23.8	20.0	13.6	17.25
H	-	-	13.5	22.1	18.0	17.0	20.2	21.4	18.6	21.7	21.2	24.1	19.0	11.6	19.03
I	13.0	14.5	12.7	22.2	17.8	16.7	19.6	22.0	17.5	21.4	21.1	21.0	18.7	10.9	17.79
J	12.1	14.7	14.0	21.2	17.5	16.8	19.6	20.9	18.6	21.8	20.9	24.6	19.6	11.6	18.14
date average	10.82	12.03	12.66	20.04	16.99	16.28	18.75	20.22	18.30	21.15	20.42	22.05	19.76	12.10	
K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

lake average	17.34
main basin average	16.93
western arm average	18.32

TURBIDITY
(JTU)

SITE	DATE May 13	May 22	May 28	June 4	June 11	June 18	June 25	July 3	July 10	July 16	July 25	Aug 3	Aug 11	Sept. 16	site average
A	3.5	-	-	1.0	-	2.0	2.0	-	-	-	1.5	1.1	1.5	3.3	1.99
B	-	-	-	-	-	2.2	-	1.1	-	2.5	2.7	-	3.3	25.0	6.13
C	-	3.8	-	1.2	-	-	4.5	-	1.7	-	1.5	-	3.0	15.0	4.39
D	3.5	5.7	7.5	1.2	3.1	4.7	6.2	1.2	1.8	3.6	1.5	0.4	5.0	19.0	4.60
E	5.8	6.7	6.7	4.2	4.2	7.3	8.3	2.9	6.2	3.0	2.7	1.5	3.2	20.0	5.91
F	3.4	-	2.4	-	-	2.1	-	-	-	-	1.5	1.4	1.5	2.8	2.16
G	-	2.3	-	1.7	-	-	2.0	-	-	1.3	1.6	-	1.7	3.0	1.94
H	-	-	4.7	-	20.0	-	-	6.0	59.0	-	3.1	-	4.8	35.0	18.94
I	-	36.0	-	-	2.7	-	-	1.3	-	-	1.3	-	2.0	3.3	7.77
J	7.6	-	4.3	-	4.2	-	-	-	4.4	4.0	2.5	7.4	2.0	6.9	4.81
date average	4.76	10.9	5.12	1.86	6.84	3.66	4.60	2.50	14.62	2.88	1.99	2.36	2.80	13.33	
K	-	-	-	-	-	-	-	-	-	-	1.9	20.0	6.5	35.0	15.85
L	-	-	-	-	-	-	-	-	-	-	-	-	1.8	-	-

lake average 5.86

main basin average 3.87

western arm average 10.51

APPENDIX 5

DEFINITION OF TERMS

adsorbed: a gas, liquid or dissolved substance gathered on a surface in a condensed layer.

allochthonous: formed elsewhere than in the region where found (i.e. originating outside of the lake).

angiosperms: a flowering plant.

anion: a negatively charged ion.

anoxic: lack of oxygen.

anthropogenic: relating to or initiated due to human effects.

autochthonous: indigenous; formed where found (i.e. originating in the lake).

autolysis: the breakdown of plant or animal tissue by the action of enzymes contained in the tissue affected; self digestion.

autotrophe: an organism utilizing inorganic material as food.

benthos: the organisms living on or at the bottom of a body of water.

cation: a positively charged ion.

coccoid: a spherical bacterium.

colloidal: a substance divided into fine particles dispersed in a medium; between solution and suspension.

density slicing: using a microdensitometer to measure the transmittance of any point on a film at different wavelengths by placing a light of set illumination beneath the film and measuring the amount of light transmitted through it to a collector on the other side. In this study, the different levels of density were then illustrated as a different color.

dystrophic: water which is highly colored by humic materials.

edaphic: related to or caused by particular soil conditions.

epilithon: organisms growing on rock and stone surfaces.

epipelon: organisms growing in or on the bottom sediments of a lake.

epiphyton: organisms growing nonparasitically upon another organism, usually a plant.

euphotic zone limit: the depth at which illumination is 1% of that at the surface.

filamentous algae: a long slender cell or series of attached cells.

flagellated algae: those species which are motile with long, lash-like appendage serving as the means of locomotion.

labile: unstable; apt to lapse or change.

littoral: the area along the shore of a lake.

metaphyton: those algae not attached to any substratum but usually associated with attached algal communities (eg. epiphyton).

morphology: the form or structure of anything.

motile: moving or capable of moving spontaneously.

oxidation: the conversion of an element to its oxide; combined with oxygen.

particulate: composed of distinct particles.

pelagic: of or pertaining to open water areas.

plankton: the aggregate of passively floating or drifting organisms in a body of water (dead or alive).

redox potential: the potential for reduction to occur.

reduction: the process of changing a compound by deoxidizing or adding hydrogen.

retention co-efficient: the fraction of the nutrient load that is not lost via outflow.

septa: dividing walls or membranes in a plant or animal structure.

seston: the suspended particulate matter in natural waters including organisms, organic detritus and inorganic matter but excluding colloids and macroscopic zooplankton.

sorption: the binding of one substance by another by any mechanism.

user day: one person making one recreational visit to the lake during a 24 hour day.